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PREFACE.

THE present volume contains one report and fourteen papers presented at the Annual General Meeting of the Institute held in London on May 13th, 1943; of these, the report and nine papers were presented under the auspices of the Joint Research Committees of the Institute and the British Iron and Steel Federation. The discussion and correspondence on these papers are also included, together with the authors' replies. In addition, further correspondence on a paper included in the No. II. volume of the *Journal* for 1942 will be found in the present book, together with the authors' reply.

Section I. of this volume contains the above-mentioned material and also the Minutes of the Proceedings of the Meeting, including the Report of Council and Statement of Accounts for 1942.

Section II. is devoted to a survey of the literature on the manufacture and properties of iron and steel, and kindred subjects, and consists of a collection of abstracts of articles from the Transactions and Proceedings of scientific societies and from the technical press. This section also contains reviews of recent books and bibliographies of literature dealing with the manufacture and properties of iron and steel. The matter included in this Section has already appeared in the *Bulletin of The Iron and Steel Institute*, which is issued monthly.

In front of the title-page are inserted lists of Bibliographies, Special Reports and Translations issued by the Institute.

4, GROSVENOR GARDENS,
LONDON, S.W. 1.
September, 1943.

CONTENTS.

LIST OF PLATES.

Abbreviations used in Text.

Å.	Ångström unit(s).
A.C.	air-cooled; alternating current.
A.H.	air-hardened.
amp.	ampère(s).
amp.hr.	ampère-hour(s).
atm.	atmosphere(s) (pressure).
Bé.	Baumé (scale).
b.h.p.	brake horse-power.
B.o.T.	Board of Trade.
B.Th.U.	British thermal unit(s).
C.	centigrade (scale).
cal.	calory; calories.
c.c.	cubic centimetre(s).
c.d.	current density.
c.g.s.	centimetre-gramme-second unit(s).
cm.	centimetre(s).
coeff.	coefficient.
const.	constant(s).
c.p.	candle-power.
cu.	cubic.
cwt.	hundredweight(s).
D.C.	direct current.
dia.	diameter(s).
dm.	decimetre(s).
e.m.f.	electromotive force.
F.	Fahrenheit (scale).
ft.	foot; feet.
ft.lb.	foot-pound(s).
g.	gramme(s).
gal.	gallon(s).
H.F.	high-frequency.
h.p.	horse-power.
h.p.hr.	horse-power-hour(s).
hr.	hour(s).
in.	inch; inches.
in.lb.	inch-pound(s).
K.	absolute temperature (Kelvin scale).
kg.	kilogramme(s).
kg.cal.	kilogramme-calory; -calories.
kg.m.	kilogramme-metre(s).
km.	kilometre(s).
kVA.	kilovolt-ampère(s).
kW.	kilowatt(s).
kWh.	kilowatt-hour(s).
lb.	pound(s).
L.F.	low-frequency.
m.	metre(s).
m.amp.	milliampère(s).
mV.	millivolt(s).
max.	maximum.
mg.	milligramme(s).
min.	minimum; minute(s).
ml.	millilitre(s).
mm.	millimetre(s).
m.m.f.	magnetomotive force.
N.	normal (solution).
N.T.P.	normal temperature and pressure.
O.H.	open-hearth; oil-hardened.
O.Q.	oil-quenched.
oz.	ounce(s).
p.d.	potential difference.
*p*H	hydrogen-ion concentration.
r.p.m.	revolutions per minute.
sec.	second(s).
sp. gr.	specific gravity.
sq.	square.
T.	tempered.
temp.	temperature.
V.	volt(s).
VA.	volt-ampère(s).
Wh.	watt-hour(s).
W.G.	water gauge.
W.Q.	water-quenched.
yd.	yard(s).
°	degree(s).

SECTION I.

MINUTES OF PROCEEDINGS
AND PAPERS OF
THE IRON AND STEEL INSTITUTE.

ANNUAL MEETING
1943

MINUTES OF PROCEEDINGS

AND

PAPERS AND DISCUSSIONS

AT THE

ANNUAL MEETING, 1943.

The Seventy-Fourth Annual Meeting of The Iron and Steel Institute was held at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W. 1, on Thursday, May 13, 1943, at 2.45 p.m., Mr. James Henderson, President, occupying the Chair.

The Minutes of the previous Meeting, held at Sheffield on December 10, 1942, were taken as read and signed.

Welcome to Members attending the Meeting.

The President (Mr. James Henderson) welcomed the Members and in particular representatives from America, Belgium, China, the Fighting French, Luxemburg, Poland and other allied countries (*applause*), and expressed pleasure at the excellent attendance.

Obituary.

The President: I regret to report the death of twenty-five Members of the Institute, whose names are recorded in the Report of Council which is in your hands. In addition, I regret to have to report the death this year of two Honorary Vice-Presidents, Mr. Charles John Bagley and Mr. James A. Farrell.

Mr. Bagley died on March 1, 1943, at the age of 95. He became a Member of the Institute in 1873, and was the senior Member by very many years. He had a distinguished career in the steel industry on the North-East Coast, serving with the Consett Iron Works and Tees Bridge and later as a Director of South Durham and Managing Director of Cargo Fleet. He was elected to the Council in 1906, and became an Honorary Vice-President in 1924. The last time that most of us saw him was at the garden party at Solberge Hall, when Mr. Talbot entertained the Institute during the Middlesbrough Meeting in 1937. He was an interesting man to meet. I am afraid that to most of you he was only a name, but I

remember meeting him for many years and receiving great kindness at his hands.

Mr. Farrell died on March 29, at the age of 80. He had a distinguished career in America. In 1903 he became President of The United States Steel Products Export Company, and in 1911 President of The United States Steel Corporation, a position which he held for 21 years. He was an Honorary Vice-President of the American Iron and Steel Institute and I think we should send a cable of condolence to that Institute. (*Agreed.*) He was elected an Honorary Vice-President of our Institute in 1930.

In memory of these and others whom I have not named, I ask you to stand for a moment in silence.

The Members stood in silence for a few moments.

Honours Conferred on Members.

The President: I have some congratulations to convey in which I am sure you will be pleased to join. Dr. A. McCance and Dr. C. Sykes have been elected Fellows of the Royal Society, and we offer them our hearty congratulations. (*Applause.*) Dr. McCance occupies an outstanding position; we all know his qualities as a scientist and an investigator, and those who know him best are not surprised to hear that he is showing equal ability on the executive side. We wish him and Dr. Sykes many years of health and prosperity.

Nomination of Col. Sir Charles Wright, Bt., G.B.E., C.B., to Honorary Membership.

The Council have this afternoon decided to nominate Sir Charles Wright to be an Honorary Member of the Institute. I need not emphasise the great services which Sir Charles has rendered to our industry, for they are well known to you. He has the unique distinction of having served as Controller during both wars, and the industry owes him much for the able way in which he has carried out these exacting duties. The Institute also is much indebted to him for constant interest and assistance. It is just ten years since he retired from a most successful Presidency, and it is fitting that we should add his name to the short and distinguished list of Honorary Members. I am sure you will all join heartily in that tribute to him. (*Applause.*)

Membership of the Council.

I have also to announce (the President continued) that Mr. W. J. Brooke has been nominated an Honorary Vice-President in recognition of the many years of distinguished service which he has given to the industry and to the Institute. It is just thirty years

since he first became a Member. On behalf of us all I wish to congratulate Mr. Brooke and to assure him of our sincere good wishes. (*Applause.*)

Last autumn Mr. Richard Mather was elected a Member of Council. He joined the Institute in 1913, and is with us for the first time as a Member of Council. This afternoon the Council elected Mr. Desmond Lysaght to be a Member of Council. I congratulate these gentlemen and am sure that you will approve of our selection.

The Council are also pleased to welcome, as I am sure all the Members are, Mr. Kilby and Mr. Glenn as Honorary Members of Council in succession to Mr. Robinson and Dr. Gregory during their periods of office as Presidents of the Lincolnshire Iron and Steel Institute and the Sheffield Metallurgical Association, respectively. We shall welcome them at our Meetings. I should like to thank Mr. Robinson and Dr. Gregory for the assistance that they have given us in the course of their Honorary Membership. I have the pleasure of welcoming Mr. Albert Wright, President of the Staffordshire Iron and Steel Institute, who is with us to-day at our Annual Meeting. Mr. Wright has succeeded Mr. Bamford, to whom we are also much indebted.

Award of the Bessemer Gold Medal for 1943 to Mr. John Hampden Whiteley.

The President: The Council have decided to award the Bessemer Gold Medal for 1943 to Mr. J. H. Whiteley, of the Consett Iron Co., Ltd. (*Applause.*) Mr. Whiteley is the author of more than twenty excellent papers, and I may remind you that a term of the original conditions governing the award of this Medal is that it shall be presented "for a paper read before the Institute and having special merit and importance in connection with iron and steel manufacture." It would be invidious to name a single paper out of the many that he has contributed, but two aspects of his work to which I wish to refer in particular are his study of the acid hearth and slag and his examination of the nature of inclusions in steel. He received the Carnegie Gold Medal in 1917 for a paper entitled "The Eggertz Test for Combined Carbon in Steel," so that he started his career of distinction some time ago.

Unfortunately, Mr. Whiteley is not with us to-day, but when we come to present him with the Roll of Honour, no doubt there will be an opportunity of adding to this brief tribute.

Williams Prizes.

The President: During recent years no award of the Williams Prize has been made, but you have before you to-day a most interesting paper on "A Review of Basic Open-Hearth Practice at an Australian Plant," by Mr. R. L. Knight, of the Australian Iron and Steel Co., Ltd., which was received last year, and so it has been

decided to award a Williams Prize of £100 to Mr. Knight. It has also been decided to award a Williams Prize of £100 to Mr. A. Jackson, of the Appleby-Frodingham Steel Co., Ltd., for his excellent paper on "The Linings of Large Basic Open-Hearth Tilting Furnaces," which was printed in the No. II. *Journal* for 1942.

Presentation of the Report of Council and Statement of Accounts for 1942.

After the Secretary (Mr. K. Headlam-Morley) had submitted the Report of Council for 1942 (*see* pp. 11 P–33 P) the President called on the Hon. Treasurer, Mr. Richard Lyttelton, to present the Statement of Accounts for the year (*see* pp. 34 P–41 P).

Mr. Richard Lyttelton (Hon. Treasurer): It will be seen from the Statement of Accounts for 1942 that expenditure has been reduced by £600 and the income increased by £1036. We have added to Reserve and various Suspense Accounts £1095, leaving a balance to carry forward to the Balance Sheet of £132.

One of the chief reasons for this satisfactory result is the work of our President, who for eight years as Honorary Treasurer gave great attention to our finances during the rather anxious times when we were moving into this new building and developing the enterprises now undertaken by the Institute. I think it is he who should be presenting this Statement of Accounts, because this is indeed a case of my reaping where others have sown.

Another reason is that, in spite of the loss of 400 overseas Members owing to the war, the British membership and the number of Associates have increased, and there is also an increase in the receipts from the sales of publications. Another important cause is that, in spite of an increase in material costs, there are several items on which we have been able to reduce expenditure. I would draw attention to the Translation Service, because that is a particular concern of our Secretary, who has developed it in the face of a certain amount of doubt. That shows, instead of a net expenditure of £212, an income of £215—a very satisfactory turn-round. In this connection, I should like to pay tribute to the Secretary and his staff, particularly mentioning Mr. Chattin, the Assistant Secretary, who has done a great deal of work in this department, Mr. Ronnebeck and Dr. Dora Steiner.

Finally, the Trust Funds are in a satisfactory position, as are also our investments. These are shown in the Balance Sheet at £73,752, but on December 31 last their market value was over £10,000 in excess of that figure.

The President, in moving the adoption of the Report of Council and Statement of Accounts for 1942, stated that the Council wished to thank the Secretary and staff for their loyal services. (*Applause.*)

The motion was carried unanimously.

Ballot for the Election of New Members and Associates.

Mr. Vernon Harbord (London) and Mr. Louis Ripley (Middlesbrough), who had been appointed scrutineers of the Ballot, reported that the following 77 candidates for membership and 53 for associateship had been duly elected :

Members.

Bailes, John George	Sheffield.
Barrass, William	Sheffield.
Bishop, C. F.	Sheffield.
Blyth, Harry Douglas Stuart	London.
Bowen, Joseph Cecil	Kenton, Middlesex.
Bradford, George Henry, B.Sc. Eng.	Johannesburg, South Africa.
Bradshaw, J. S.	Sheffield.
Brearley, Alan Charles, B.Sc. (Hons. Met.)	Barnsley.
Brown, Robert James	Coventry.
Buechling, William J.	Warren, Ohio, U.S.A.
Burbage, Harold William Raymond	Corby.
Carter, William Leslie	Quinton, Birmingham.
Chalmers, William James	Birmingham.
Chrimes, Neville Walter David, B.Sc. (Birmingham)	Cradley Heath, Staffs.
Clarke, W. Herbert Victor	Wolverhampton.
Cordero, Harry George	Eynsham, Oxfordshire.
Cornwall, E. S., A.M.I.E. (Aus.)	Brisbane, Australia.
Dale, Frank Wilson, B.Sc., A.I.C.	Norwich.
Davis, Emrys	Wrexham.
Dean, William Thomas, B.Sc. (Manchester), A.I.C.	Carshalton, Surrey.
Dickinson, Edward Cyril, M.Met. (Sheffield), A.M.I.A.E.	Hampton-in-Arden, Warwickshire.
Doughty, John Arton Francis	Burton Green, Warwickshire.
Dyal, S. J.	Sheffield.
Eastwood, La Verne W., M.S., Ph.D.	Baltimore, Md., U.S.A.
Fassotte, Paul Charles	Ashorne Hill, Leamington Spa.
Fells, Henry Alexander, B.Sc., Ph.D., A.I.C., A.M.I.Min.E.	Sheffield.
Fisk, Phillip Marcus, Ph.D., B.Sc., A.I.C.	Braintree.
Francis, Sydney	Weeton, Leeds.
Franks, Russell Minor	Niagara Falls, N.Y., U.S.A.
Fry, C. L.	Sheffield.
Grünfeld, Herbert	London.
Harpham, Edward William	Sheffield.
Higgins, Patrick Daniel, A.R.S.M., B.Sc. (Met.),(London)	Port Talbot.

Hughes, Martin Luther, M.Sc. (London), F.I.C.	Cwmgwyn, Swansea.
Ibbotson, Leslie Simpson, A.M.C.T.	Bristol.
Jackson, John Fabian Brindley, B.Sc. (Hons. Met.), A.I.C.	Sheffield.
Jeffries, Harry Farmery	Karabuk, Turkey.
Jennings, Alfred Cameron	Allestree, Derby.
Knight, George Allen, Assoc. Met. (Sheffield)	Oxford.
Kosarski, Zbigniew Z. J.	Thurlstone, Sheffield.
Lacy-Hulbert, Cyril, M.A. (Cantab.)	Aston, Birmingham.
Lewandowski, *W/Cdr.* Mieczyslaw	London.
Lowery, Harry, M.Ed. (Leeds), M.Sc., Ph.D. (London), D.Sc. (Manchester), F.Inst.P.	London.
Macdonald, Alexander Craig, B.Sc., A.M.I.A.E.	Scotstoun, Glasgow.
MacEwan, John Hay	Hillington, Glasgow
Marsh, Tom Henry	Hightown, Wrexham.
Mason, Anthony	Sheffield.
Mellor, Gilbert Arthur	Hampton Hill, Middlesex.
Metcalfe, John Wallace, B.A.	Sydney, Australia.
Mingay, George William, B.A. (Oxon.)	Sheffield.
Moody, Geoffrey Williamson, A.M.I.Mech.E.	Manchester.
Mort, E. G.	Briton Ferry.
Mowat, James Mowat, B.Sc. (Met.) (London)	Bearsden, Dumbartonshire.
Murfitt, George, A.I.C., Assoc. Met. (Sheffield)	Totley Rise, Sheffield.
Palmer, Gerald Stanley	Sheffield.
Randle, James	Letchworth.
Richards, Edward Samuel	Walsall.
Risdon, Robert Beadon Hamilton	Wolverhampton.
Roberts, Thomas	Wrexham.
Robertson, Harry Alexander	Glasgow.
Robinson, F. W.	Sheffield.
Sachs, Werner, Ph.D.	London.
Sargeant, Henry Grant	Sheffield.
Scott, John Rowland Andrew	Manchester.
Staniland, Harold Wells	Scunthorpe.
Stayman, Thomas Henry, A.M.Inst.C.E.	Thornaby-on-Tees.
Stubbs, R.	Bradford.
Stubbs, Ross Lewis	Oxford.
Taylor, Philip Herbert, A.M.C.T.	Worsley, Lancs.
Thomas, Henry Glynn	Llanelly.
Thomson, James	Corby.
Wade, Sidney Arthur	Thornton Heath, Surrey.
Walker, John, B.Sc. (Eng.), A.R.S.M.	New Malden, Surrey.
Walters, Francis Marion, jun., Ph.D.	Washington, U.S.A.

WARK, *Dr.* I. W.	Fishermen's Bend, Victoria, Australia.
WINSOR, KEITH WILLIAM	North Carlton, Victoria, Australia.
YOUNG, EDGAR	Netherton, Dudley.

ASSOCIATES.

AIRSTON, JOHN BRIAN	New Barnet.
ANTHONY, SAMUEL CLIFFORD	Liverpool.
BADONE, LOUIS	Uplands, Swansea.
BAGGLEY, THOMAS	Workington.
BARCLAY, THOMAS MORTON	Bilston.
BARRACLOUGH, KENNETH CHARLES, B.Sc., Assoc. Met. (Sheffield), A.I.C.	Chapeltown, Sheffield.
BRIDGE, FRANCIS DOWNIE	Bridge-of-Weir.
BRYAN, RAYMOND VERNON	Kings Norton, Birmingham.
BULLIVANT, DEREK JIM	S. Yardley, Birmingham.
BURKS, HERBERT GEORGE	Brynmill, Swansea.
COTTRELL, C. L. M.	Stafford.
COUTTS, DONALD KERR, B.Sc., A.I.C.	Belfast.
EDWARDS, JOHN ORMEROD	Stockton Heath, Warrington.
FENTON, GEOFFREY	Leeds.
FLETCHER, WALLACE JOHN	Patchway, Bristol.
FONTAINE, KENNETH	Scunthorpe.
FORREST, KENNETH JOSEPH	Erdington, Birmingham.
GUNN, KENNETH WILLIAM	Swansea.
HILL, JOHN DIXON	Sketty, Swansea.
HOSELITZ, KURT, Ph.D. (Bristol)	Sheffield.
HOWES, RICHARD SIDNEY, B. Met.	Sheffield.
HUGHES, DAVID EMRYS RICHARD	Birmingham.
IRVINE, KENNETH JAMES	Leeds.
KING, GEORGE ROLAND	Hounslow, Middlesex.
KUBILINS, *Ensign* EDWARD THEODORE, U.S.N.R.	Princeton, N.J., U.S.A.
LEWIS, ROBERT BROOK	South Yarra, Victoria, Australia.
LISTER, RICHARD PERCIVAL	Farnborough, Hants.
MALLIK, ASIT KUMAR	Sheffield.
MARSH, WALTER DOUGLAS	Coventry.
MIDDLETON, JAMES MAURICE	Sheffield.
MORRIS, ALBERT	Port Talbot.
MORTIMORE, R. W. N.	Scunthorpe.
MURDOCH, ARTHUR WHOODS	Wombourn, Wolverhampton.
MURPHY, PHILIP CONWAY	Uplands, Swansea.
NUTTING, JACK	Mirfield, Yorkshire.
PEASE, RENDEL SEBASTIAN	Aylesbury.
PETCH, *Mrs.* MARION KATHARINE	Fleet, Hants.
PHILLIPS, EDMOR	Swansea.
PRICE, BARTLETT R., B.S.	Pittsburgh, Pa., U.S.A.
RAGG, KENNETH MARTIN	Whitburn, Co. Durham.

SEAGER, GEORGE CRESSWELL, Ph.D., M.Sc.	Stoke-on-Trent.
SHAW, DAVID	Leeds.
SLOAN, JOHN	Clydebank.
SNOWDEN, DOUGLAS RONALD CLAYFIELD	London.
STONE, HOWARD EDWARD NAGLE	Skewen, Glam.
TATAM, NOEL CURTIS	Peterborough.
TAYLOR, ROBERT RONALD	Larbert, Stirlingshire.
TOWERS, *Miss* HELEN	Larbert, Stirlingshire.
TROTMAN, GEOFFREY EDWARD	Oldbury, Birmingham.
WAIN, HENRY LAURENCE	Melbourne, Australia.
WATSON, BASIL ARTHUR	Scunthorpe.
WHITE, GEORGE J.	Southport.
WILLIAMS, DEREK HOWARD	Leeds.

ELECTION OF VICE-PRESIDENTS AND MEMBERS OF COUNCIL.

The SECRETARY (Mr. K. Headlam-Morley): In accordance with Bye-Law 10, the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting, 1942, as being due to retire at the present Annual Meeting:

Vice-Presidents: Mr. Arthur Dorman, Mr. J. S. Hollings and Mr. Fred Clements.

Members of Council: Professor J. H. Andrew, Mr. P. B. Brown, Mr. J. R. Menzies-Wilson, Captain H. Leighton Davies, C.B.E., and Mr. I. F. L. Elliot.

As no other Members have been nominated, they are, in accordance with the Bye-Laws, re-elected.

PRESENTATION OF PAPERS.

A list of all the papers included in the programme of the Meeting will be found on p. 9 P. The following were presented for verbal discussion:

"First Report of the Marine Corrosion Sub-Committee." (Paper No. 9/1943 of the Corrosion Committee (submitted by the Marine Corrosion Sub-Committee)).

"A Review of Basic Open-Hearth Practice at an Australian Plant," by R. L. KNIGHT.

VOTES OF THANKS.

The PRESIDENT moved a vote of thanks to the authors for their papers.

On the motion of Dr. C. H. DESCH, F.R.S. (Vice-President), seconded by Dr. W. H. HATFIELD, F.R.S. (Vice-President), a vote of thanks was accorded to the President for his conduct in the Chair.

The proceedings then terminated.

Complete List of Papers and Report Presented at the Annual General Meeting, 1943.

"First Report of the Marine Corrosion Sub-Committee." (Paper No. 9/1943 of the Corrosion Committee (submitted by the Marine Corrosion Sub-Committee)).

C. R. Barber: "The Calibration of the Platinum/13%-Rhodium–Platinum Thermocouple over the Liquid Steel Temperature Range." (Paper No. 17/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Liquid Steel Temperature Sub-Committee)).

C. A. Edwards, F.R.S., D. L. Phillips and Y. H. Liu: "The Yield Point in Steel."

R. L. Knight: "A Review of Basic Open-Hearth Practice at an Australian Plant."

T. Land: "Thermal Stresses in Ingot Moulds." (Paper No. 20/1943 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Stresses in Moulds Panel of the Ingot Moulds Sub-Committee, a Joint Sub-Committee of the Heterogeneity and Open-Hearth Committees)).

F. László: "Tessellated Stresses.—Part I."

F. László: "Graphitisation of Steel Influenced by Tessellated Stresses."

R. H. Myers: "A Review of the Work of the Ingot Moulds Sub-Committee." (Paper No. 19/1943 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Ingot Moulds Sub-Committee, a Joint Sub-Committee of the Heterogeneity and Open-Hearth Committees)).

N. J. Petch: "The Positions of the Carbon Atoms in Martensite."

A. Preece: "The Desirability of Removing Sulphur from Gaseous Fuels for Heating Ferrous Metal." (Paper No. 10/1943 of the Alloy Steels Research Committee).

G. C. Seager and F. C. Thompson: "The Influence of Temperature on the Modulus of Elasticity of some Plain and Alloy Steels." (Paper No. 9/1943 of the Alloy Steels Research Committee).

H. T. Shirley and E. Elliott: "A Critical Consideration of some Applications of the Spectrograph to Steelworks Analysis." (Paper No. 18/1943 of the Committee on the Heterogeneity of Steel Ingots (submitted by Dr. W. H. Hatfield, F.R.S.)).

L. R. Stanton: "A Recording Dilatometer for Metal Specimens." (Paper No. 7/1942 of the Alloy Steels Research Committee (submitted by Professor F. C. Thompson)).

N. Stuart and U. R. Evans: "The Effect of Zinc on the Corrosion-Fatigue Life of Steel." (Paper No. 8/1943 of the Corrosion Committee).

F. C. Thompson and N. C. Saha: "Thermo-Electric Power of very Pure Iron between 20° and 230° C." (Paper No. 8/1943 of the Alloy Steels Research Committee).

REPORT OF COUNCIL FOR 1942.

THE Council submit this, their Annual Report and Statement of Accounts for the year 1942 to Members for their approval at the Seventy-Fourth Annual General Meeting of The Iron and Steel Institute. Information up to 31st March, 1943, has been included in some sections of the Report.

Increased use of all facilities provided by the Institute was made during the year by Members and Companies in the iron and steel industry. Although the Annual and Autumn Meetings were again on the reduced scale suitable to war-time conditions, attendances and discussions were good. A number of Meetings with Local Societies were again held in accordance with the Council's policy of providing opportunities for technical discussion in steelmaking districts.

The *Journal* and *Monthly Bulletin of Abstracts* were published as usual and numerous additions made to the list of translations of foreign technical articles which are now provided. The total of volumes loaned by the Library increased by 5% over the record figure of the previous year, and there was an increase also in the number of enquiries dealt with by the Information Department.

The Research Committees for which the Institute is responsible continued their investigations and issued a number of important Reports for publication. The work of these Committees now constitutes one of the major activities on which the Institute is engaged. Although the tendency was for each group of investigators to meet less frequently, the total number of meetings, at seventy-five, exceeded by eleven the number held during the previous year. Programmes have been adjusted to meet war-time conditions and now consist largely of items of immediate importance. The increased interest in the work of these Committees is, in the opinion of the Council, satisfactory evidence of the way in which the Institute is assisting the industry by encouraging both long-term research and the solution of problems of more immediate interest.

ROLL OF THE INSTITUTE.

There was an increase of thirty-two in the number of Members and, although the total is still below the record reached before the war, the position is considered satisfactory in view of the considerable drop in membership in Continental countries. The steady increase in the number of British and Associate Members is evidence of the use made of the Institute by metallurgists and those engaged in the British iron and steel industry. Details compared with those of the three preceding years are given in Table I. Varia-

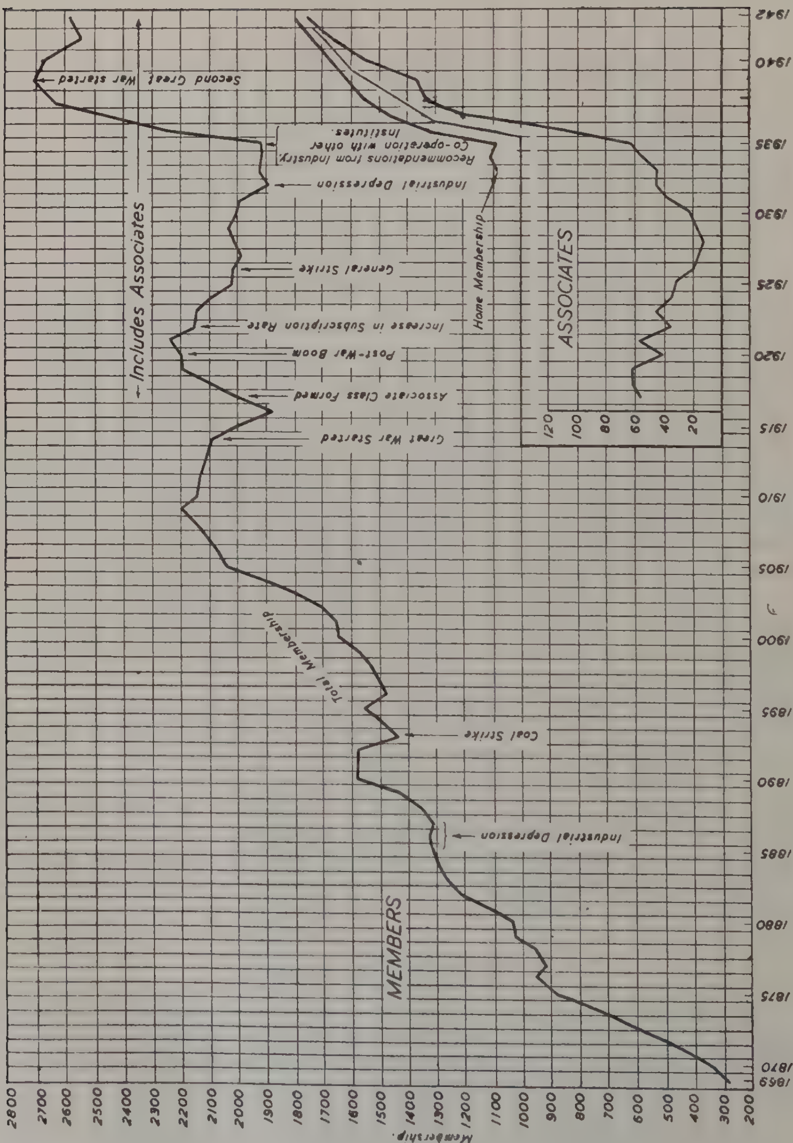

FIG. 1.—Variation in Membership since the Foundation of the Institute in 1869.

tions in the Membership since the formation of the Institute in 1869 are shown in Fig. 1.

TABLE I.—*Membership at* 31*st December*, 1942, *and Preceding Three Years.*

	31/12/'39.	31/12/'40.	31/12/'41.[1]	31/12/'42.
Patron	1	1	1	1
Honorary Members	15	14	15	14
Life Members	68	67	60	60
Ordinary Members:[2]				
Home	1622	1673	1698	1753
Overseas	785	663	515	460
Associates	213	248	262	295
Total	2704	2666	2551	2583

[1] Revised.

[2] The above figures include six Members for 1942 and eight for the other years whose names were retained in the List of Members in an honorary capacity by order of the Council.

The current Roll of Members does not include those who have been placed on Suspense Lists. The total number placed on these owing to absence on military duties or for similar reasons was forty-two as at 31st December, 1942 (compared with thirty as at 31st December, 1941). In addition, thirty-two more Members and one Associate resident in China and Hong Kong or in occupied or neutral countries on the Continent were also placed on a Suspense List as from 1st January, 1942, making the total in this category two hundred and forty-nine (compared with two hundred and twenty-five as at 1st January, 1941, after adjustments for deaths and reinstatements). The result is that only those Members resident on the Continent whose subscriptions have been paid to date are included in the current Roll of Members. The number of former Members who are enemy aliens and whose membership has terminated under By-Law No. 36 was one hundred and twenty-one at 31st December, 1942.

During the year twenty-one Members and one Associate resigned and the deaths of twenty-five Members were reported. One hundred and thirty-five Members and seventy-eight Associates were elected or reinstated; these include thirty-nine Members and ten Associates nominated by Companies which subscribe to the Special Subscription Fund and thirty-three Members and thirty-five Associates who joined under the scheme of collaboration with the Institute of Metals.

As will be seen from Table II., 27% of the total number of Members at the end of the year were also Members of the Institute of Metals; this compares with 25% at the end of the previous year (revised figure).

TABLE II.—*Composition of Membership at 31st December*, 1942.

	Home Members.		Overseas Members.		Total.	
	Ordinary.	Joint.[1]	Ordinary.	Joint.[1]	Ordinary.	Joint.[1]
Patron	1	...	...	...	1	...
Honorary Members	4	1	8	1	12	2
Life Members	33	6	16	5	49	11
Ordinary Members [2]	1353	400	339	121	1692	521
Total (Members)	1391	407	363	127	1754	534
Associates	119	142	15	19	134	161
Total (classified)	1510	549	378	146	1888	695
Total membership					2583	

[1] Members who are also Members of the Institute of Metals.
[2] Includes six Members whose names were retained in the List of Members in an honorary capacity by order of the Council.

OBITUARY.

The Council regret to record the deaths of the following twenty-two Members which occurred during the year 1942:

ALLEN, WATSON (Rotherham)	29th February.
ATHA, C. G. (Milnthorpe, Westmorland)	4th November.
BECKET, Dr. F. M. (New York, U.S.A.)	1st December.
BINGHAM, JOHN WILLIAM (Sheffield)	27th September.
BIRKBECK, HENRY (London)	29th June.
BOOTE, E. M. (Birmingham)	15th May.
BUTLER, *Major* B. H. (Leeds)	29th July.
GARRETT, G. B. (Cleveland, Ohio, U.S.A.)	24th September.
GLASS, DAVID K. (Carmyle, Lanarkshire)	23rd March.
GOODISON, W. S. (Sheffield)	13th February.
HARBORD, F. W., C.B.E. (London) (*Past President*)	27th December.
LLOYD, G. C. (London) (*Hon. Secretary*)	10th July.
LOEWY, L. (Bournemouth)	10th October.
MOSS, F. C. (Rotherham)	17th June.
NORRIS, GEORGE L. (New York, U.S.A.)	13th April.
PRENTICE, *Captain* D. R. C. (Doncaster)	?
ROSS, DAVID (Stockton-on-Tees)	23rd October.
SCHNEIDER, C. P. EUGÈNE (Paris, France) (*Past-President*)	17th November.
SMITH, R. PERCIVAL (Sheffield)	19th March.
SQUIRE, C. E. (Sheffield)	30th September.
STANFIELD, G. (Sheffield)	20th November.
WRAITH, *Major* H. O. (Bulawayo, Southern Rhodesia)	2nd August.

The deaths of the following three Members took place earlier than 1942, but were not previously reported :

Dennis, C. C. (New York, U.S.A.)	November, 1941.
Forsberg, U. (Gothenburg, Sweden)	23rd March, 1941.
Mosscrop, A. M. (New York, U.S.A.)	March, 1941.

Mr. Harbord and Dr. Schneider were Past-Presidents of the Institute; Dr. Becket, Mr. Forsberg and Mr. Percival Smith were well-known figures among steelmakers in America, in Sweden and in Great Britain. Mr. Atha, Mr. Bingham and Mr. Boote had been Members for twenty-five years or more, Major Butler, Mr. Mosscrop and Major Wraith over thirty years, and Mr. Birkbeck for fifty-three years. Mr. Lloyd had been Secretary of the Institute for twenty-four years, a longer period than any of his three predecessors.

Obituary notices will be found in the No. II. volume of the *Journal* for the year.

Since the end of the year the Council have learned with regret of the deaths of Mr. C. J. Bagley and Mr. James A. Farrell, Honorary Vice-Presidents, on 1st March and 29th March, 1943, respectively.

Finance.

(*The Statement of Accounts for* 1942 *is attached to this Report.*)

A sound financial position has been maintained in spite of the loss of membership and increased costs directly attributable to the War. It is the policy of the Council to build up reserves against the additional expenditure which will be necessary after the War, and in particular to ensure that sufficient sums are available to meet the cost of repairs and decorations to the Institute's building, which cannot now be undertaken, and to enable the Library to be brought fully up to date. Substantial sums have been placed to the credit of these as well as of other reserve accounts.

General Fund.—As a result of economies made, expenditure decreased substantially while income from normal sources, including particularly membership subscriptions and sale of *Journals*, increased. After allocating £1095 to various reserve accounts a balance of £132 excess of income over expenditure was carried to the Balance Sheet.

Trust Funds.—Few applications for scholarships from the Andrew Carnegie Trust Fund were received, with the result that the income of this Fund exceeded expenditure by £845. No award of the Williams Prize was made during the year, and the income of the Williams Prize fund accordingly exceeded expenditure by £122.

Investments.—The value of investments of the General Fund and Trust Funds at the end of the year was £73,752; their market value exceeded their cost, at which they are taken into the Balance Sheet, by a total of £10,760.

House Fund and Industrial Subscriptions.—Income from special subscriptions was £4506, an increase of £119 over the previous year. New subscribers included: William Jessop & Sons, Ltd., and the South Wales Siemens Steel Association.

The Council again wish to express their appreciation of the generous response to their appeal for industrial subscriptions. The following is a list of Companies and Associations from which contributions were received during the year: Edgar Allen & Co., Ltd.; Ashmore, Benson, Pease & Co., Ltd.; Babcock and Wilcox, Ltd.; Bairds and Scottish Steel, Ltd.; Baldwins, Ltd.; Arthur Balfour & Co., Ltd.; Frederick Braby & Co., Ltd.; Bradley and Foster, Ltd.; The Briton Ferry Steel Co., Ltd.; Burnell & Co., Ltd.; The Butterley Co., Ltd.; Bynea Steel Works, Ltd.; Colvilles, Ltd.; Consett Iron Co., Ltd.; The Darlington Forge, Ltd.; The Darwen and Mostyn Iron Co., Ltd.; Darwins, Ltd.; Dorman, Long & Co., Ltd.; English Steel Corporation, Ltd.; Thos. Firth and John Brown, Ltd.; General Refractories, Ltd.; Guest Keen Baldwins Iron and Steel Co., Ltd.; J. J. Habershon & Sons, Ltd.; Hadfields, Ltd.; N. Hingley & Sons, Ltd.; William Jessop & Sons, Ltd.; Kayser, Ellison & Co., Ltd.; The Lancashire Steel Corporation, Ltd.; Arthur Lee & Sons, Ltd.; The Llanelly Steel Co. (1907), Ltd.; John Lysaght, Ltd.; McCall & Co. (Sheffield), Ltd.; The Millom and Askam Hematite Iron Co., Ltd.; The Mond Nickel Co., Ltd.; Neepsend Steel and Tool Corporation, Ltd.; Newton Chambers & Co., Ltd.; The Oughtibridge Silica Firebrick Co., Ltd.; The Park Gate Iron and Steel Co., Ltd.; The Patent Shaft and Axletree Co., Ltd.; Raine & Co., Ltd.; Round Oak Works, Ltd.; Simon-Carves, Ltd.; Walter Somers, Ltd.; The South African Iron and Steel Industrial Corporation, Ltd.; South Durham Steel and Iron Co., Ltd.; The South Wales Siemens Steel Association; The Stanton Ironworks Co., Ltd.; The Steetley Lime and Basic Co., Ltd.; John G. Stein & Co., Ltd.; Stewarts and Lloyds, Ltd.; John Summers & Sons, Ltd.; Tata, Ltd.; Taylor Bros. & Co., Ltd.; Richard Thomas & Co., Ltd.; The Tinsley Rolling Mills Co., Ltd.; The Union Steel Corporation (of South Africa), Ltd.; The United Steel Companies, Ltd.; The Upper Forest and Worcester Steel and Tinplate Works, Ltd.; Vickers, Ltd.; The Wellman Smith Owen Engineering Corporation, Ltd.; The Welsh Plate and Sheet Manufacturers' Association; Whitehead Iron and Steel Co., Ltd.; The Woodall-Duckham Vertical Retort and Oven Construction Co. (1920), Ltd.

Changes on the Council.

(*To 31st March*, 1943).

During the year Mr. Richard Mather (Messrs. Pease and Partners, Ltd., and The Skinningrove Iron Co., Ltd.) was elected a Member of Council. Mr. Joseph Needham Kilby (Messrs. Richard Thomas

and Co., Ltd., Redbourn Works, Scunthorpe), Mr. George Glenn (Tinsley Wire Industries, Ltd., Sheffield) and Mr. Albert Wright (Messrs. Stewarts and Lloyds, Ltd., Bilston) accepted invitations to become Honorary Members of Council during their Presidencies of the Lincolnshire Iron and Steel Institute, the Sheffield Metallurgical Association and the Staffordshire Iron and Steel Institute in succession to Mr. A. Robinson (as from 1st April, 1943), Dr. E. Gregory (as from 1st January, 1943) and Mr. G. R. Bashforth (as from 12th June, 1942), respectively.

In accordance with Bye-Law No. 10, the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting as being due to retire at the Annual General Meeting in 1943 :

Vice-Presidents : Mr. Arthur Dorman, Mr. J. S. Hollings and Mr. Fred Clements.

Members of Council : Professor J. H. Andrew, Mr. P. B. Brown, Mr. J. R. Menzies-Wilson, Captain H. Leighton Davies, C.B.E., and Mr. I. F. L. Elliot.

No other Members having been nominated up to one month previous to this Annual Meeting, the retiring Members are presented for re-election.

Bessemer Gold Medal.

The Bessemer Gold Medal for 1942 was awarded to Mr. Eugene Gifford Grace, Eng.D. (President of the Bethlehem Steel Corporation), in recognition of the great services which he had rendered to the iron and steel industries in America and in appreciation of his work in fostering scientific and technical collaboration between the industries in Great Britain and the United States.

Honorary Member.

The President announced at the Annual Meeting that the Council had invited Mr. Harry Brearley, of Sheffield, a Bessemer Gold Medallist, to become an Honorary Member.

Andrew Carnegie Medal. Williams Prize.

No award of the Andrew Carnegie Medal or of the Williams Prize was made during the year.

Sheffield University : "The Iron and Steel Institute" Prize.

When the Degree Course in Foundry Metallurgy at Sheffield University was instituted in 1934, the Council of the Institute offered an annual Prize, to a value not exceeding ten guineas, to be awarded to the best student of the year, as shown by the marks gained in the Final Examination; the Prize was made available for

five years in the first instance, its continuation to be considered by the Council of the Institute after the close of that period.

The first occasion on which the Prize was awarded was 1938, and the following students have won the Prize in that and subsequent years :

1938	Vincent J. D. Hill.
1939	William H. Moore.
1940	No Award.
1941	J. H. Woodhead.
1942	L. G. Finch.
	P. K. Gledhill.

Andrew Carnegie Research Scholarships.

Grants were made by the Council in 1942 to the following candidates :

H. J. Merchant (Messrs. S. D. F. (Kidderminster), Ltd., Kidderminster)—£100 in aid of an investigation of the attributes of electrolytic polishing for ferrous metallography.

B. H. Mason (Stockholm University, Sweden)—£50 in aid of an investigation of the $FeO–Fe_2O_3–MnO–Mn_2O_3$ system.

The Worshipful Company of Blacksmiths.

No recommendation for admission to the Worshipful Company of Blacksmiths was made during the year.

Honours Conferred on Members.

(*To* 31*st March,* 1943).

The Council tender their warm congratulations to the following Members of the Institute on honours and appointments received during the period under review :

Balfour, The Hon. Robert A. Re-elected Senior Warden of the Cutlers' Company.

Briggs, A. G. E. Appointed Deputy Controller, Iron and Steel Supplies, Ministry of Supply.

Brown, Engineer Vice-Admiral Sir Harold. Appointed Senior Supply Officer, Ministry of Supply.

Bruce-Gardner, Sir Charles. Appointed Chairman of a Board set up by the Ministry of Aircraft Production to advise on the economic use of man-power in the aircraft industry.

Burton, G. D. Created a Knight Bachelor.

Campbell, Major J. M., O.B.E., M.C. Appointed Joint Deputy Controller, Raw Materials, Iron and Steel Control, Ministry of Supply.

CHIPMAN, Dr. JOHN. Selected to deliver the Campbell Memorial Lecture to the American Society of Metals, 1942.

CLARK, Major R. P. Awarded the Greek Medal.

COLCLOUGH, Dr. T. P. Appointed Technical Adviser to the Iron and Steel Control, Ministry of Supply.

DOREY, Dr. S. F. Member of a Ministry of Supply Panel to study air-conditioning of vehicles, particularly tanks.

DUNBAR, A. Created a Knight Bachelor. Appointed Controller-General, Ministry of Aircraft Production.

DUNCANSON, J. M. Created a Knight Bachelor. Appointed Controller of Iron and Steel, Ministry of Supply.

ELLIS, Professor O. W. Awarded the Duggan Medal and Prize of the Engineering Institute of Canada for his paper on "The Forgeability of Metals."

FEARNEHOUGH, W. Appointed a Justice of the Peace for Sheffield.

GLENN, G. Elected President of the Sheffield Metallurgical Association.

GOUGH, Dr. H. J., M.B.E., F.R.S. Created a Companion of the Order of the Bath.

GREGORY, Dr. E. Elected Member of Council of the Institution of Engineering Inspection.

HOSKISON, T. Elected Honorary Treasurer of the Staffordshire Iron and Steel Institute.

HURST, Dr. J. E. Elected Junior Vice-President of the Staffordshire Iron and Steel Institute.

HUTTON, Professor R. S. Elected Prime Warden of the Worshipful Company of Goldsmiths for the year 1942–43.

KILBY, J. N. Elected Chairman of the Lincolnshire Ironmasters' Association and President of the Lincolnshire Iron and Steel Institute.

LAYCOCK, COLIN. Appointed Justice of the Peace for Sheffield.

LEA, Professor F. C. Elected President of the Institution of Mechanical Engineers.

LE TALL, S. H. Elected President of the Crucible Steelmakers' Association.

LEWIS, ESSINGTON. Appointed Director General of Aircraft Production in the Commonwealth of Australia.

LYSAGHT, DESMOND R. Appointed Sheriff of Monmouthshire for 1942.

MCCANCE, Dr. A. Appointed a Member of the Advisory Council to the Committee of the Privy Council for Scientific and Industrial Research. Elected a Fellow of the Royal Society.

MCCOSH, A. K. Elected a Vice-President of the Mining Association of Great Britain.

MERICA, Dr. P. D. Awarded the Franklin Gold Medal jointly with Professor J. C. Hunsaker. Elected an Honorary Member of the Franklin Institute.

MOORE, Dr. HAROLD, C.B.E. Awarded the Institute of Metals Platinum Medal for 1943.

NIJHAWAN, Dr. B. RAJ. Appointed Assistant Inspection Officer, Government Metallurgical Inspectorate (Government of India), Tatanagar.

PREECE, A. Appointed Senior Lecturer in Metallurgy in the University of Leeds.

REES, EDGAR G. Elected President of the National Federation of Iron, Steel and Metal Merchants. Re-elected President of the Monmouthshire Iron and Steel Scrap Merchants' Association.

RIVERDALE OF SHEFFIELD, The Right Hon. Lord, LL.D. Created a Knight Grand Cross of the Order of the British Empire.

SANKEY, Colonel H. B. Appointed Regional Controller of Production for the Midlands.

SENIOR, Major E. W., J.P. Re-elected Searcher of the Cutlers' Company for the year. Appointed a Member of the Combined Steel Committee.

SUMMERS, GEOFFREY, D. L. Created a Commander of the Order of the British Empire.

SYKES, Dr. C. Elected a Fellow of the Royal Society.

THOMAS, B. Elected Senior Vice-President of the Staffordshire Iron and Steel Institute.

TURNER, T. HENRY. Awarded the Thomas Howe Gray Prize for 1942 by the Institution of Mechanical Engineers for his paper on "Corrosion of Boiler Tubes."

WATERHOUSE, Dr. G. B. Transferred from War Production Board to Lease-Lend Administration, Washington; special consultant on iron, steel and other metals.

WHEELER, C. R. Appointed Joint Deputy Controller, Raw Materials, Iron and Steel Control, Ministry of Supply.

WINDER, A. B. Created a Knight Batchelor. Re-elected Searcher of the Cutlers' Company for the year. Appointed Justice of the Peace for Sheffield.

WOLFF, Lieut.-Colonel M. A., O.B.E. Appointed a Magistrate of the City of Birmingham.

WOOD, W. W., J.P. Re-elected Master Cutler for 1942–43; fourth term of office.

WRIGHT, A. Elected President of the Staffordshire Iron and Steel Institute.

WRIGHT, Colonel Sir W. CHARLES, Bt., K.B.E., C.B. Created a Knight Grand Cross of the Order of the British Empire.

A number of Members continued to serve in the Iron and Steel Control and in other Departments of the Ministry of Supply, &c. Colonel Sir W. Charles Wright, Bt., G.B.E., C.B., resigned his position as Controller of Iron and Steel, and was succeeded by Sir John Duncanson; owing to the latter's absence on a mission, Sir Charles again undertook the duties of Controller. Mr. A. K. McCosh resigned his position of Deputy Controller, Raw Materials, Iron and Steel Control, and was succeeded by Major J. M. Campbell, O.B.E., M.C., and Mr. C. R. Wheeler, as Joint Deputy Controllers. Mr. A. G. E. Briggs was appointed Deputy Controller, Iron and Steel Supplies.

Staff.

The Council wish to express their appreciation of the services rendered by the Secretary and staff which have enabled the work of the Institute to be continued in spite of substantial reduction in the number of those employed. Lieut. H. Davison was promoted captain in the Pioneer Corps, and Mr. H. G. Hale was granted a commission in the Royal Artillery. Miss M. J. Bradford joined the Auxiliary Territorial Service.

Meetings.

Annual Meeting.

The Annual Meeting was held at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on Thursday, 7th May, 1942. Mr. John Craig, C.B.E., D.L., President, was in the Chair at the beginning of the proceedings, his place being taken later by Mr. James Henderson, President-Elect. Eleven papers, including six submitted under the auspices of Joint Research Committees of the Institute and the British Iron and Steel Federation, were presented, and four papers were discussed during the Meeting.

Autumn Meeting.

The Autumn Meeting of the Institute was held at the Royal Victoria Station Hotel, Sheffield, on Thursday, 10th December, 1942, the President, Mr. James Henderson, being in the Chair. By arrangement, the Meeting was a Joint Meeting with the Sheffield Society of Engineers and Metallurgists, the Sheffield Metallurgical Association and the Sheffield Branches of the Institute of British Foundrymen and the Refractories Association of Great Britain. Seventeen papers were presented, including eleven submitted by Joint Research Committees of the Institute and the British Iron and Steel Federation, and six were discussed at the Meeting.

Relations with other Societies and Technical Institutions.

(*For the period* 1*st April*, 1942, *to* 31*st March*, 1943.)

As far as war-time conditions permitted, friendly relations were maintained with Scientific Societies and Technical Institutions in the

Dominions, allied and neutral countries. In particular, close contact was maintained with Societies in the U.S.A. and the Council wish to record their pleasure in having been able to welcome a number of distinguished Americans visiting this country on official missions. Close collaboration with the Institute of Metals was continued on the lines of previous years, and it is the policy of both Councils to extend this in as far as the interests of the Members of the two Institutes are concerned. Five hundred and thirty-four Members and a hundred and sixty-one Associates were also Members of the Institute of Metals, an increase of fifty-two over the total of six hundred and forty-three reported a year ago (revised figure; not eight hundred and sixty-one as previously stated).

Friendly contact with other Scientific Societies and Technical Institutions in Great Britain was also maintained, and in particular the Council record with pleasure the continued friendly relations existing with the following Societies on the same basis as in previous years:

Cleveland Institution of Engineers.
Ebbw Vale Metallurgical Society.
Lincolnshire Iron and Steel Institute.
Manchester Metallurgical Society.
Newport and District Metallurgical Society.
Sheffield Metallurgical Association.
Sheffield Society of Engineers and Metallurgists.
Staffordshire Iron and Steel Institute.
Swansea Technical College Metallurgical Society.
West of Scotland Iron and Steel Institute.

Joint Meetings.

The following are particulars of Joint Meetings held with Local Societies:

Tuesday, 19th May, 1942: The Sheffield Society of Engineers and Metallurgists, The Sheffield Metallurgical Association and The Refractories Association of Great Britain.

Place and Time: Royal Victoria Station Hotel, Sheffield, at 5.30 P.M.

Chairman: Dr. W. H. Hatfield, F.R.S., Vice-President of The Iron and Steel Institute; President of The Sheffield Society of Engineers and Metallurgists.

Subject for Discussion: "Open-Hearth Furnace Refractories," in two parts, (*a*) "Dolomite Bricks" and (*b*) "Open-Hearth Roofs, including Temperature Control." The discussion was based on the following recent publications of the Institute:

(a) *Dolomite Bricks.*

(1) "The Stabilisation of Dolomite—Laboratory Studies," introduced by Dr. J. R. Rait. (Basis: Section B, Paper No. 2 of the "Second Report on Refractory Materials" (*The Iron and Steel Institute*, 1942, *Special Report No.* 28).)

(2) "Dolomite Bricks for Use in Steelworks," introduced by Dr. T. Swinden. (Basis: "Dolomite Bricks for Use in Steelworks," by T. Swinden, D.Met., and J. H. Chesters, Ph.D., B.Sc. (*Journal of The Iron and Steel Institute*, 1941, No. II., pp. 105P–118P).)

(3) "Semi-Stable Dolomite Bricks," introduced by Dr. W. J. Rees. (Basis: Section B, Paper No. 3 of the "Second Report on Refractory Materials.")

(b) *Open-Hearth Roofs, including Temperature Control,* introduced by Dr. T. Swinden.

(4) "Low-Temperature Roof Pyrometry.—Thermocouple Control in Heating up Furnaces," introduced by Mr. T. R. Lynam. (Basis: "A Co-operative Investigation of the Factors influencing the Durability of the Roofs of Basic Open-Hearth Furnaces" (*Journal of The Iron and Steel Institute*, 1941, No. II., pp. 203P–262P).)

(5) "High-Temperature Roof Pyrometry.—The Use of Roof Pyrometers in Maturing the Roof and Increasing its Life," introduced by Mr. A. E. Dodd. (Basis: The above-mentioned paper on Basic Open-Hearth Roofs.)

(6) "The Microstructure of Used Roof Bricks," introduced by Mr. W. Hugill. (Basis: Section VI. of the above-mentioned paper on Basic Open-Hearth Bricks.)

Wednesday, 24th June, 1942: The Sheffield Society of Engineers and Metallurgists, The Sheffield Metallurgical Association and The South Yorkshire Section of The Institute of Chemistry.

Place and Time: Royal Victoria Station Hotel, Sheffield, at 7 P.M.

Chairman: Dr. W. H. Hatfield, F.R.S., Vice-President of The Iron and Steel Institute; President of The Sheffield Society of Engineers and Metallurgists.

Papers:

"First Report of the Standard Methods of Analysis Sub-Committee." (Presented by Dr. E. Gregory, Chairman of the Sub-Committee.)

"On the Carbide and Nitride Particles in Titanium Steels," by W. Hume-Rothery, M.A. (Oxon.), D.Sc. (Oxon.), F.R.S., G. V. Raynor, M.A. (Oxon.), Ph.D. (Oxon.), and A. T. Little, B.Sc. (Glasgow). (Presented by Dr. A. H. Jay.)

Wednesday, 30th September, 1942: Manchester Metallurgical Society.

Place and Time: The Engineer's Club, Albert Square, Manchester, at 6.30 P.M.

Chairman: Mr. J. Sinclair Kerr, Member of Council of The Iron and Steel Institute.

Paper:

"The Work-Hardening and Ageing of Steel," by Professor J. H. Andrew, D.Sc., and H. Lee, Ph.D., B.Eng.

Saturday, 24th October, 1942 : The Sheffield Society of Engineers and Metallurgists and The Sheffield Metallurgical Association.

Place and Time : Royal Victoria Station Hotel, Sheffield, at 2.30 P.M.

Chairman : Dr. W. H. Hatfield, F.R.S., Vice-President of The Iron and Steel Institute ; President of The Sheffield Society of Engineers and Metallurgists.

Papers :

"The Determination of the Solubility of Hydrogen in Iron and Iron Alloys," by Professor J. H. Andrew, D.Sc., H. Lee, B.Eng., Ph.D., and A. G. Quarrell, B.Sc., Ph.D.

"The Formation of Hair-Line Cracks.—Part I.," by Professor J. H. Andrew, D.Sc., A. K. Bose, B.Met., G. A. Geach, M.Sc., Ph.D., and H. Lee, B.Eng., Ph.D.

"The Formation of Hair-Line Cracks.—Part II.," by Professor J. H. Andrew, D.Sc., A. K. Bose, B.Met., Ph.D., H. Lee, B.Eng., Ph.D., and A. G. Quarrell, Ph.D., F.Inst.P.

Tuesday, 17th November, 1942 : The Lincolnshire Iron and Steel Institute.

Place and Time : The Modern School, Cole Street, Scunthorpe, Lincolnshire, at 7.30 P.M.

Chairman : Mr. A. Robinson, President of The Lincolnshire Iron and Steel Institute.

Papers :

"The Linings of Large Basic Open-Hearth Tilting Furnaces," by A. Jackson.

"Investigations on 'Falling' Blast-Furnace Slags," by T. W. Parker, M.Sc., Ph.D., A.I.C., and J. F. Ryder, B.Sc.

Monday, 14th December, 1942 : The Cleveland Institution of Engineers.

Place and Time : The Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough, at 6.30 P.M.

Chairman : Mr. L. F. Wright, President of The Cleveland Institution of Engineers.

Paper :

"The Linings of Large Basic Open-Hearth Tilting Furnaces," by A. Jackson.

Thursday, 4th February, 1943 : The Staffordshire Iron and Steel Institute.

Place and Time : The Dudley and Staffordshire Technical College, The Broadway, Dudley, at 6.45 P.M.

Chairman : Mr. A. Wright, President of The Staffordshire Iron and Steel Institute.

Lecture : On "Rimming Steel" by Mr. James Mitchell.

Saturday, 13th February, 1943 : The Sheffield Metallurgical Association, The Sheffield Society of Engineers and Metallurgists and the South Yorkshire Section of The Institute of Chemistry.

Place and Time : The Royal Victoria Station Hotel, Sheffield, at 2.30 P.M.

Chairman : Dr. W. H. Hatfield, F.R.S., Vice-President of The Iron and Steel Institute ; President of The Sheffield Society of Engineers and Metallurgists.

Paper :

"A Critical Consideration of some Applications of the Spectrograph to Steelworks Analysis," by H. T. Shirley, B.Sc., A.R.C.S., and E. Elliott, A.Met.

Thursday, 25th February, 1943 : The Ebbw Vale Metallurgical Society.

Place and Time : The Workman's Hall, Ebbw Vale, at 7 P.M.

Chairman : Mr. Norman R. James, Chairman of The Ebbw Vale Metallurgical Society.

Lecture : On "Rimming Steel" by Mr. James Mitchell.

Local Members of the Institute were invited to attend a Meeting of the Sheffield Society of Engineers and Metallurgists at the Royal Victoria Station Hotel, Sheffield, on 26th September, 1942, at 2.30 P.M., when Dr. H. Sutton (Royal Aircraft Establishment, Farnborough) gave a lecture on "Steels in German Aero-Engines and Aircraft."

In addition, the Institute took part in a Meeting organised by the Sheffield Metallurgical Association at the Sheffield Metallurgical Club, 198 West Street, Sheffield, on 10th October, 1942, at 2.30 P.M., at which Dr. W. H. Hatfield, F.R.S. (Vice-President of the Institute), gave an address on "The Rationalisation of Specifications to Meet War-Time Needs."

Members resident in the Sheffield district were also invited to attend a Meeting of the Sheffield Society of Engineers and Metallurgists at the Royal Victoria Station Hotel, Sheffield, on 12th December, 1942, at 2.30 P.M., at which a lecture on "Economic Utilisation of Alloy Steel Scrap" was given by Mr. H. Bull (Messrs. Brown, Bayley's Steel Works, Ltd., Sheffield).

The Meetings were well supported and the discussions interesting. The Council desire once again to put on record their thanks to the Presidents, Councils and Secretaries of the Local Societies, as well as to the authors of the papers.

PUBLICATIONS.

Papers and Committee Reports.—Two volumes of the *Journal* and *Special Report No.* 28, "Second Report on Refractory Materials," were published during the year. The two issues of the *Journal* contained Mr. Henderson's Presidential Address, twelve papers issued under the auspices of the Joint Research Committees of The

Iron and Steel Institute and The British Iron and Steel Federation, four Sub-Committee Reports and eleven papers, as follows:

- JAMES HENDERSON: "Presidential Address."
- "First Report of the Standard Methods of Analysis Sub-Committee." (Paper No. 11/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Standard Methods of Analysis Sub-Committee)).
- "Protective Painting of Structural Steel." By the Protective Coatings Sub-Committee. (Paper No. 5/1941 of the Corrosion Committee (submitted by the Protective Coatings Sub-Committee)).
- "Second Report of the Moulding Materials Sub-Committee." (Paper No. 3/1942 of the Steel Castings Research Committee (submitted by the Moulding Materials Sub-Committee)).
- "Third Report of the Liquid Steel Temperature Sub-Committee." (Paper No. 9/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Liquid Steel Temperature Sub-Committee)).
- Professor J. H. ANDREW, D.Sc., A. K. BOSE, B.Met., G. A. GEACH, M.Sc., Ph.D., and H. LEE, B.Eng., Ph.D. (The University of Sheffield): "The Formation of Hair-Line Cracks. Part I." (Paper No. 5/1942 of the Alloy Steels Research Committee (submitted by the Hair-Line Crack Sub-Committee)).
- Professor J. H. ANDREW, D.Sc., A. K. BOSE, B.Met., Ph.D., H. LEE, B.Eng., Ph.D., and A. G. QUARRELL, Ph.D., F.Inst.P. (The University of Sheffield): "The Formation of Hair-Line Cracks.—Part II." (Paper No. 6/1942 of the Alloy Steels Research Committee (submitted by the Hair-Line Crack Sub-Committee)).
- Professor J. H. ANDREW, D.Sc., and H. LEE, Ph.D., B.Eng. (The University of Sheffield): "The Work-Hardening and Ageing of Steel."
- Professor J. H. ANDREW, D.Sc., H. LEE, B.Eng., Ph.D., and A. G. QUARRELL, B.Sc., Ph.D. (The University of Sheffield): "The Determination of the Solubility of Hydrogen in Iron and Iron Alloys." (Paper No. 4/1942 of the Alloy Steels Research Committee (submitted by the Hair-Line Crack Sub-Committee)).
- Professor J. H. ANDREW, D.Sc., and H. T. PROTHEROE, B.Sc. (The University of Sheffield): "Investigation of the Influence of Mould Friction on Tearing in Castings." (Paper No. 2/1941 of the Steel Castings Research Committee).
- D. BINNIE, Ph.D. (Lancashire Steel Corporation, Ltd., Irlam, near Manchester): "An Ingot of Rimmed Steel made by the Basic Open-Hearth Process." (Paper No. 13/1942 of the Committee on the Heterogeneity of Steel Ingots).
- G. R. BOLSOVER and S. BARRACLOUGH (Messrs. Samuel Fox & Co., Ltd.): "The Influence of Tin on Alloy Steels."
- H. J. GOLDSCHMIDT, M.Sc. (Research Department, Messrs. William Jessop & Sons, Ltd., Sheffield): "The Crystal Structures of Fe, FeO and Fe_3O_4 and their Interrelations."
- J. C. HUDSON, D.Sc., A.R.C.S., T. A. BANFIELD, Ph.D., A.R.C.S., and H. A. HOLDEN, B.Sc., A.R.C.S. (Birmingham): "Tests on the Corrosion of Buried Ferrous Metals." (Paper No. 6/1942 of the Corrosion Committee (submitted by the Sub-Committee on the Corrosion of Buried Metals)).
- WILLIAM HUME-ROTHERY, M.A. (Oxon.), D.Sc. (Oxon.), F.R.S., GEOFFREY VINCENT RAYNOR, M.A. (Oxon.), Ph.D. (Oxon.), and ALEXANDER TORRANCE LITTLE, B.Sc. (Glasgow) (Inorganic Chemistry Laboratory, University Museum, Oxford): "On the Carbide and Nitride Particles in Titanium Steels."
- WILLIAM HUME-ROTHERY, M.A. (Oxon.), D.Sc. (Oxon.), F.R.S., GEOFFREY VINCENT RAYNOR, M.A. (Oxon.), Ph.D. (Oxon.), and

Alexander Torrance Little, B.Sc. (Glasgow) (Inorganic Chemistry Laboratory, University Museum, Oxford): "The Lattice Spacings and Crystal Structure of Cementite."

A. Jackson (Appleby-Frodingham Steel Co., Ltd., Scunthorpe): "The Linings of Large Basic Open-Hearth Tilting Furnaces."

C. H. M. Jenkins, D.Sc., G. A. Mellor, M.Sc., and E. A. Jenkinson, B.Sc. (National Physical Laboratory, Teddington): "Investigation of the Behaviour of Metals under Deformation at High Temperatures. Part II.—Structural Changes in Carbon Steels caused by Creep and Graphitisation."

F. A. Lemon, M.I.Mech.E., and Hugh O'Neill, M.Met., D.Sc. (London, Midland and Scottish Railway Company, Derby): "The Production in Rotary Furnaces of Steel for Castings," with Appendices by T. Fletcher and J. N. Bradley, A.R.S.M., B.Sc.

J. Mitchell (Messrs. Stewarts and Lloyds, Ltd.): "Rimming Steel. Comparative Study of Three Ingots received from Soc. Anon. des Hauts Fourneaux, Forges et Aciéries de Denain et d'Anzin at Denain, France." (Paper No. 12/1942 of the Committee on the Heterogeneity of Steel Ingots).

J. Mitchell (Messrs. Stewarts and Lloyds, Ltd.): "Rimming Steel. Report on Four Ingots of Basic Bessemer Steel." (Paper No. 14/1942 of the Committee on the Heterogeneity of Steel Ingots).

D. A. Oliver, M.Sc., F.Inst.P., and T. Land, M.A. (Research Department, Messrs. Wm. Jessop & Sons, Ltd., Sheffield): "The Temperature Distribution in the Liquid Steel in Various Steelmaking Furnaces." (Paper No. 10/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Liquid Steel Temperature Sub-Committee)).

T. W. Parker, M.Sc., Ph.D., A.I.C., and J. F. Ryder, B.Sc. (Building Research Station, D.S.I.R., Garston, Herts.): "Investigations on 'Falling' Blast-Furnace Slags."

N. J. Petch, B.Sc., B.Met. (Cavendish Laboratory, Cambridge): "The Positions of the Carbon Atoms in Austenite."

H. Schubert, M.A., D.Phil. (Reading University): "The First Cast-Iron Cannon made in England."

T. Swinden, D.Met. (Director of Research, The United Steel Companies, Ltd., Stocksbridge, near Sheffield): "Rimming Steel.—Additional Studies of the Composition Variation from Outside to Centre." (Paper No. 15/1942 of the Committee on the Heterogeneity of Steel Ingots).

T. Swinden, D.Met., and W. W. Stevenson, A.I.C. (The United Steel Companies, Ltd., Stocksbridge, near Sheffield): "A Note on Diffusion in Rimming Steel on Soaking at about 1300° C." (Paper No. 16/1942 of the Committee on the Heterogeneity of Steel Ingots).

R. S. Thornhill, Ph.D., and U. R. Evans, Sc.D. (Cambridge University): "A Study of some Soluble Inhibitors, with Special Reference to Heat Transfer and Water-Line Attack." (Paper No. 7/1942 of the Corrosion Committee).

The Bulletin of The Iron and Steel Institute was published monthly during the year; as usual it was reprinted as Section II. of the *Journals* issued for the corresponding periods. The *Bulletin* is supplied free of charge to Members on application; the subscription rate to non-members is 30*s*. per annum ($6 to members of the American Iron and Steel Institute, the American Institute of Mining and Metallurgical Engineers and the American Society for Metals).

Translation Service.—Translations of fifty-five foreign technical papers were prepared and included in the Institute's Translation

Series; they are obtainable by Members at 10*s.* each (5*s.* for each additional copy of the same translation).

Members requiring translations of foreign technical papers are invited to communicate with the Secretary. Those that are suitable will be included in the Translation Series and will be supplied at the rates indicated above; it may be possible to prepare others at the Member's expense.

In recent volumes of the *Journal* the translations issued during the period covered by the volume have been listed on pages preceding the title page.

Joint Library and Information Department.

Joint Library.

It is the policy of the Council to keep the Joint Library as fully up to date as circumstances permit, and accordingly increased funds have been made available for the purchase of text-books and periodicals. The Council wish to take this opportunity of thanking those from whom presentations were received. A list of the additions made to the Library is issued quarterly and copies will be sent to Members on request. Arrangements were made to enable certain German technical periodicals to be available for loan, and translations of these can be supplied; a number of German text-books were purchased. Good use was again made of the Library by Companies and Government Departments as well as by Members of the Institute and of the Institute of Metals; 6284 volumes were sent out on loan during 1942, an increase of 5% on the former record number of 5949 during the previous year. The majority of articles abstracted in the *Bulletin of The Iron and Steel Institute* are filed in the Library and are available on loan. The original articles can in most cases be purchased for Members on request, and photographic copies can be supplied under certain conditions.

Micro-Film Service.

A service for the supply of micro-films was started in conjunction with ASLIB and the Science Library, South Kensington. By the generosity of the Rockefeller Foundation a number of reading instruments were placed at the disposal of the Royal Society. One of these instruments was allocated to The Iron and Steel Institute and placed in the Joint Library, so that it is now possible for Members and representatives of Companies either to read micro-films in the reading room or to obtain them for use with their own instruments. Members in possession of micro-film copies of foreign technical journals are invited to deposit them in the Library and to give permission to make them available to others wishing to inspect them.

Collaboration with the Institute of Civil Engineers and the Science Library.

The valuable collections of scientific works included in the Science Library and the Library of The Institution of Civil Engineers are available for consultation or loan under certain conditions. Members who wish to avail themselves of these facilities should communicate with the Librarian of the Joint Library, 4 Grosvenor Gardens, London, S.W.1.

Information Department.

The Information Department has dealt with an increased number of enquiries, and bibliographies have been compiled at the request of Members. Members are invited to avail themselves of the bibliographical and information services.

RESEARCH.

Collaboration with the Iron and Steel Industrial Research Council was continued on the same basis as in former years.

The following is a list of the Joint Committees of the Institute and the British Iron and Steel Federation, reporting to the Iron and Steel Industrial Research Council, and of their Sub-Committees; the number of meetings recorded in 1942 was 75 (56 in 1939; 59 in 1940; 64 in 1941):

Alloy Steels Research Committee : Chairman, Dr. W. H. Hatfield, F.R.S. Established June, 1934. Meetings held during 1942 : four.

Thermal Treatment Sub-Committee : Chairman, Mr. P. B. Henshaw. Established January, 1936. No meetings held during 1942 ; activities carried on by correspondence.

Hair-Line Crack Sub-Committee : Chairman, Dr. W. H. Hatfield, F.R.S. Established July, 1938. Meetings held during 1942 : four.

Special Aero-Components Sub-Committee : Chairman, Dr. W. H. Hatfield, F.R.S. Established July, 1940. Meetings held during 1942 : (not recorded).

Corrosion Committee : Chairman, Dr. W. H. Hatfield, F.R.S. Established July, 1928. Meetings held during 1942 : four.

Laboratory (Corrosion) Research Sub-Committee : Chairman, Dr. U. R. Evans ; Acting Chairman, Dr. G. D. Bengough, F.R.S. Established June, 1930. No meetings held during 1942 ; activities carried on by correspondence.

Protective Coatings Sub-Committee : Chairman, Mr. T. M. Herbert. Established January, 1936. Meetings held during 1942 : two.

Marine Corrosion Sub-Committee : Chairman, Dr. G. D. Bengough, F.R.S. Re-formed November, 1938. Meetings held during 1942 : nine.

Sub-Committee on Low-Alloy Steels : Established June, 1938. No meetings held during 1942 ; activities carried on by correspondence.

Sub-Committee on the Corrosion of Buried Metals (working in collaboration with the Committee on Soil Corrosion of Metals and Cement Products of The Institution of Civil Engineers): Established October, 1937. No meetings held during 1942; activities carried on by correspondence.

Heterogeneity of Steel Ingots Committee : Chairman, Dr. W. H. Hatfield, F.R.S. Established May, 1924. Meetings held during 1942 : four.

Ingot Moulds Sub-Committee (formed jointly by the Committee on the Heterogeneity of Steel Ingots and the Open-Hearth Committee of the Iron and Steel Industrial Research Council): Chairman, Mr. R. H. Myers. Established November, 1934. Meetings held during 1942: two. (Stresses in Moulds Panel, one.)

Joint Sub-Committee on the Physical Chemistry of Steelmaking (formed jointly by the Committee on the Heterogeneity of Steel Ingots and the Open-Hearth Committee of the Iron and Steel Industrial Research Council): Chairman, Dr. T. Swinden. Established, 1938. No meetings held during 1942.

Liquid Steel Temperature Sub-Committee : Chairman, Mr. E. W. Elcock. Established March, 1929. Meetings held during 1942 : two.

Oxygen Sub-Committee : Chairman, Dr. T. Swinden. Established January, 1936. Meetings held during 1942 : two. (Chemists' Panel, five.)

Inclusions Sub-Committee : Chairman, Dr. W. H. Hatfield, F.R.S. Established November, 1936. Meetings held during 1942 : four.

Standard Methods of Analysis Sub-Committee : Chairman, Dr. E. Gregory. Established September, 1939. Meetings held during 1942 : nine.

Steel Castings Research Committee : Chairman, Mr. W. J. Dawson. Established November, 1934. Meetings held during 1942 : five.

Moulding Materials Sub-Committee : Chairman, Dr. W. J. Rees. Established March, 1936. Meetings held during 1942 : six.

Foundry Practice Sub-Committee : Chairman, Mr. F. Cousans. Established May, 1938. Meetings held during 1942 : seven.

Foundry Steel Temperature Sub-Committee : Chairman, Mr. D. A. Oliver. Established December, 1941. Meetings held during 1942 : five.

Appointment of Representatives.

The following is a list of the Institute's representatives on various governing bodies and committees for the year 1943; it has been brought up to date to 31st March, 1943 :

British Association, Fuel Economy Committee : *appointment open.*

BRITISH CAST IRON RESEARCH ASSOCIATION: Professor T. Turner.

BRITISH CORPORATION REGISTER OF SHIPPING AND AIRCRAFT, Technical Committee: Dr. A. McCance, F.R.S.

BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCIATION,

- Sub-Committee J/E, Joint Committee, Steels for High Temperatures: Dr. W. H. Hatfield, F.R.S., Dr. T. Swinden.
- Sub-Committee J, Earthing to Water Mains: Dr. J. C. Hudson.

BRITISH IRON AND STEEL FEDERATION, Statistical Committee: Mr. K. Headlam-Morley.

BRITISH REFRACTORIES RESEARCH ASSOCIATION, Council: Mr. W. J. Brooke.

BRITISH STANDARDS INSTITUTION,

- Chemical Engineering Divisional Council: Mr. E. F. Law.
- Engineering Divisional Council E/-: The Hon. R. G. Lyttelton, Dr. T. Swinden and Mr. K. Headlam-Morley.
- Sub-Committee M33/7, Protective Glasses for Welders and Industrial Purposes: Dr. C. H. Desch, F.R.S.
- Sub-Committee C/25/10, Painting of Iron and Steel: Mr. F. Fancutt, Mr. R. A. Hacking.
- Technical Committee CEB/1, Cement: *appointment open.*
- Technical Committee CEB/6/1, Concrete Blocks: *appointment open.*
- Technical Committee CH/17, Symbols used in Diagrams of Chemical Engineering Plant: Mr. A. E. Chattin.
- Technical Committee EL/28, Fans: Mr. A. F. Webber.
- Iron and Steel Industry Committee IS/-: Dr. T. Swinden.
- Technical Committee IS/1, Co-ordination of Iron and Steel Specifications: Dr. T. Swinden.
- Technical Committee IS/6, Steel Castings: Dr. R. H. Greaves.
- Technical Committee IS/8, Creep Properties: Dr. W. H. Hatfield, F.R.S.
- Technical Committee IS/15, Iron and Steel for Shipbuilding: Sir Edward J. George.
- Technical Committee IS/17, Cast Iron Columns for Street Lighting: Mr. J. G. Pearce.
- Technical Committee IS/35, Cast Iron: *appointment open.*
- Technical Committee IS/35/3, Malleable Steel Castings: Mr. C. H. Kain.
- Technical Committee ME/22, Marking and Colouring of Foundrymen's Patterns: *appointment open.*
- Technical Committee ME/23, Brinell Hardness Testing: Dr. W. H. Hatfield, F.R.S.

Technical Committee ME/25, Testing of Thin Metal Sheet and Strip : Dr. T. Swinden.

Technical Committee ME/32, Engineering Symbols and Abbreviations : Dr. T. Swinden.

Solid Fuel Industry Committee, SF/- : Mr. A. F. Webber.

Technical Committee SF/1, Nomenclature and Definitions : Mr. A. F. Webber.

Technical Committee SF/2, Underfed Screw Type Stokers : Mr. A. F. Webber.

Technical Committee SF/4, Heating Stoves : Mr. A. F. Webber.

Technical Committee on Metallic Finishes : Mr. F. C. Platt.

Units and Technical Data Co-ordinating Committee : Sir Wm. Larke, K.B.E.

City and Guilds of London Institute, Advisory Committee on Metallurgy : Mr. E. C. Greig.

Constantine College, Advisory Committee : Mr. E. W. Jackson.

Empire Council of Mining and Metallurgical Institutions : Mr. K. Headlam-Morley (*one appointment open*).

Engineering Public Relations Committee,
Main Committee : Mr. James Henderson.
Executive Committee : Mr. K. Headlam-Morley.

Hong-Kong University, Home Committee : *appointment open.*

Imperial College of Science and Technology, Board of Governors : Mr. James Henderson.

Imperial Institute, Mineral Resources Department, Iron and Ferro-Alloy Metals Committee : Mr. K. Headlam-Morley.

Institute of Fuel, Council : Dr. R. J. Sarjant.

Institute of Welding, Council and Representative of Patron Institution : Mr. K. Headlam-Morley.

Institution of Mechanical Engineers, Research Committee on High-Duty Cast Irons for General Engineering Purposes : Dr. J. E. Hurst.

Iron and Steel Industrial Research Council : Dr. W. H. Hatfield, F.R.S., Mr. K. Headlam-Morley, the Hon. R. G. Lyttelton.

Joint Committee on Materials and their Testing : Mr. K. Headlam-Morley.

Liverpool University, Court of Governors : Sir W. Peter Rylands, Bt.

Lloyd's Register of Shipping, Technical Committee : Mr. James Henderson, Mr. P. Baxter.

National Physical Laboratory, General Board : Dr. W. H. Hatfield, F.R.S., Professor J. H. Andrew.

Parliamentary and Scientific Committee : Mr. K. Headlam-Morley.

Ramsay Memorial Laboratory, Advisory Committee : *appointment open.*

ROYAL SCHOOL OF MINES, Advisory Board: *appointment open.*
ROYAL SOCIETY, General Board for Administering Government Grants for Scientific Investigations: The President.
SCHOOL OF METALLIFEROUS MINING (CORNWALL), Board of Governors: Mr. J. S. Hollings.
SCIENCE MUSEUM, Advisory Council: *appointment open.*
SHEFFIELD UNIVERSITY, Court of Governors: Sir Arthur B. Winder, J.P.

[The Statement of Accounts for 1942 will be found in the following pages.]

THE IRON AND

BALANCE SHEET,

LIABILITIES.

	£	s.	d.	£	s.	d.	£	s.	d.
Sundry Creditors :—									
Office Rent ...				300	0	0			
Telephone Calls and Telegrams ...				31	12	8			
Travelling Expenses ...				50	1	0			
Autumn Meeting ...				10	12	4			
Heating and Lighting ...				150	6	6			
Bulletin ...				78	8	10			
Staff Superannuation ...					7	6			
Subscriptions in Suspense ...				36	15	4			
Income Tax—Staff Deductions ...				131	5	4			
Printing and Stationery ...				12	4	5			
Air Raid Precautions ...				2	7	8			
							804	1	7
Subscriptions in Advance :—									
Home Members ...				56	19	3			
Overseas Members ...				44	7	3			
Associates ...				11	10	0			
							112	16	6
Journal Sales :—									
Amount in advance 1943 ...				30	6	6			
Received on account of No. II., 1942 ...				104	5	9			
Miscellaneous ...				5	11	5			
Bulletin ...				4	17	6			
Translations ...				2	0	0			
							147	1	2
Bank Overdraft—Secretary's Account ...							40	8	9
Suspense Account as at 1st January, 1942 :—	£	s.	d.						
Reserve for 10-year Index ...	350	0	0						
Add Further Transfer, 1942 ...	50	0	0						
				400	0	0			
Bessemer Gold Medal ...	25	0	0						
Add Further Transfer, 1942 ...	25	0	0						
				50	0	0			
Library Account ...	500	0	0						
Add Further Transfer, 1942 ...	250	0	0						
				750	0	0			
Repairs and Decorations ...	1,161	0	5						
Add Further Transfer, 1942 ...	538	19	7						
				1,700	0	0			
							2,900	0	0
Entrance Fees Reserve Fund ...				2,407	3	6			
Add Further Transfer, 1942 ...				189	1	2			
							2,596	4	8
Life Composition Fund ...				3,259	14	8			
Add Compounded during year ...				42	0	0			
							3,301	14	8
Iron and Steel Institute :—									
Capital as per last Balance Sheet ...				23,882	2	4			
Accumulated excess of Income over Expenditure ...	£ 1,634	s. 3	d. 3						
Add Excess of Income over Expenditure for the year ...	132	5	3						
				1,766	8	6			
							25,648	10	10
							£35,550	18	2

We have examined the above Balance Sheet

224 Regent Street,
London, W.1.
March, 1943.

STEEL INSTITUTE.

31st DECEMBER, 1942.

ASSETS.

	£ s. d.	£ s. d.	£ s. d.
Sundry Debtors :—			
Subscriptions in arrear			Not valued.
Amount due from Carnegie Scholarship Fund		136 0 0	
Travelling Expenses		103 17 7	
Telephone		8 15 3	
Sales		126 3 4	
Sundries		34 10 9	
Income Tax Recoverable		1,637 9 7	
Institute of Metals :—	£ s. d.		
Rent	187 10 0		
Joint Library	56 5 0		
Heating	23 0 0		
Salaries	68 0 0		
		334 15 0	
Translations Service		27 7 6	
			2,408 19 0
Payments in Advance :—			
Publishing Expenses :—	£ s. d.		
Printing	28 16 0		
Reviews	1 1 0		
Advance Copies	87 11 1		
		117 8 1	
Insurance		56 18 4	
Library Books		26 2 6	
Staff Superannuation Fund		103 6 4	
Salaries and Pensions		13 17 1	
Rates		14 11 11	
			332 4 3
Stock of Journals			Not valued.
Office Furniture and Library			Not valued.
Cash at Bank and in Hand :—			
Deposit Account		2 0 4	
Post Office Savings Bank Deposit Account		18 13 2	
General Account		1,501 2 7	
Cash at Office		16 9 3	
			1,538 5 4
Investments at Cost per Schedule :—			
General Fund ... ... (The Market value of these Investments at 31st December, 1942, was £31,792 0s. 10d.)			27,904 15 4
Joint Research Committees :—			
Amount advanced			64 19 7
Life Composition Fund :—			
Investments at Cost per Schedule ... ... (The Market value of these Investments at 31st December, 1942, was £3,497 18s. 8d.)			3,301 14 8
			£35,550 18 2

of the Institute and certify it to be correct.

(*Signed*) W. B. KEEN & Co.,
Chartered Accountants.

INCOME.

1941. £	£		£ s. d.	£ s. d.	£ s. d.
112		Entrance Fees	107 3 2		
92		Do. Companies Nominations	81 18 0	189 1 2	
204	—	*Less* Transfer to Reserve Fund		189 1 2	—
		Annual Subscriptions :—			
4,567		Members, Home Current		4,805 15 0	
94		Do. Companies' Nominations		116 11 0	
384		Do. Arrears		219 19 6	
	5,045				5,142 5 6
1,012		Members, Overseas Current		935 7 10	
37		Do. Companies' Nominations		5 5 0	
101		Do. Arrears		188 8 4	
	1,150				1,129 1 2
212		Associates, Current		261 8 6	
21		Do. Companies' Nominations		10 10 0	
13		Do. Arrears		19 19 0	
	246				291 17 6
		Sales of Publications :—			
929		Journals, etc.		961 11 1	
84		Bulletin		78 19 6	
117		Translations		450 6 7	
1,130				1,490 17 2	
489		*Less* Bad Debts written off		139 11 4	
	641				1,351 5 10
		Interest on Investments (Gross) :—			
1,066		General Fund		1,106 7 2	
123		Life Composition Fund		123 9 8	
16		Bessemer Medal Fund		16 0 0	
	1.205				1,245 16 10
	28	Interest on Deposit Accounts			19 14 3
	19	Sundry Receipts			23 19 9
		Institute of Metals :—			
750		Rent Receivable		750 0 0	
400		Contribution to Joint Library	400 0 0		
50		*Less* Refund	25 0 0		
				375 0 0	
	1,100				1,125 0 0
		Iron and Steel Industrial Research Council :—			
750		Grant for Bulletin		750 0 0	
2,500		Grant for Secretarial Services		2,500 0 0	
500		Grant for Information Service		500 0 0	
	3,750				3,750 0 0
	100	British Iron and Steel Corporation, Ltd., *re* distribution of Basic Refractories			50 0 0
	—	Sales of Waste Paper			36 9 9
	4,784	Balance, being excess of Expenditure over Income carried down			3,295 19 0
	£18,068				£17,461 9 7

£	£		£ s. d.	£ s. d
		Special Subscriptions :—		
2,905		Contributions received during 1942	2,992 14 6	
1,482		Income Tax Recoverable	1,513 13 4	
4,387			4,506 7 10	
35		*Less* Legal Expenses	—	
	4,352			4,506 7 10
	751	Balance, being excess of Expenditure over Income		—
	£5,103			£4,506 7 10

EXPENDITURE.

1941. £	£		£ s. d.	£ s. d.	£ s. d.
7,436		Salaries (including Pensions and Overtime) ...		7,524 5 9	
435		War Bonus		475 17 9	
7,871				8,000 3 6	
733		*Less* Contribution from Ministry of Supply and British Iron and Steel Corporation, Ltd. ...	875 0 0		
150		Do. Andrew Carnegie Research Fund	150 0 0	1,025 0 0	
	6,988				6,975 3 6
	55	National Insurance			60 5 7
	307	Staff Superannuation Fund			404 15 0
	1,200	Office Rent			1,200 0 0
	273	Repairs and Decorations and Air Raid Precautions			79 15 0
	959	Cleaning, Heating, Lighting and Water ...			888 9 8
	237	Library Books			489 13 5
	30	Office Furniture			30 3 6
	183	Annual Meeting			26 19 10
	10	Autumn Meeting			43 2 8
		Publishing Expenses :—			
1,419		Journal : Printing and Paper		1,415 13 9	
176		Postage		141 17 10	
251		Advance Copies : Printing		138 6 2	
140		Postage		40 14 5	
439		Bulletin : Printing		458 14 7	
110		Postage		64 1 2	
310		Reports and Bibliographies		5 14 6	
330		Translation Service		245 3 1	
	3,175				2,510 5 6
	539	Stationery and Printing			547 16 11
	422	Postage and Receipt Stamps			586 3 6
395		Travelling and Entertainment Expenses ...		429 3 0	
33		*Less* Recoverable from Ministry of Supply ...		103 17 7	
	362				325 5 5
86		Insurance		59 14 4	
237		Do. War Damage		101 11 8	
	323				161 6 0
	44	Auditors' Fee for 1941			43 10 0
	159	Telephone Rental and Calls			204 5 2
	134	Office Disbursements and Sundry Expenses ...			237 17 11
	2	Bessemer Gold Medal			—
		Grants :—			
50		British Electrical and Allied Industries Research Association		50 0 0	
25		British Refractories Research Association ...		25 0 0	
10		Joint Committee on Materials and their Testing		1 1 0	
50		British Standards Institution		50 0 0	
10		Mellor Memorial		10 0 0	
11		Parliamentary and Scientific Committee ...		10 10 0	
10		Foundry Prize		—	
	166				146 11 0
	2,500	Iron and Steel Industrial Research Council—Grant			2,500 0 0
	£18,068				£17,461 9 7
£	£		£ s. d.	£ s. d.	£ s. d.
	4,784	Balance brought down			3,295 19 0
		Transfer Reserve and Suspense Account :—			
—		Repairs and Decorations		538 19 7	
—		Library		250 0 0	
50		Ten-year Index		50 0 0	
25		Bessemer Gold Medal		25 0 0	863 19 7
	75				
		Companies' Nominations :—			
92		Entrance Fees		81 18 0	
		Subscriptions Account :—			
94		Home Members	116 11 0		
37		Overseas Members	5 5 0		
21		Associates	10 10 0	132 6 0	
	244				214 4 0
	—	Balance, being excess of Income over Expenditure for the year			132 5 3
	£5,103				£4,506 7 10

WILLIAMS PRIZE FUND.

BALANCE SHEET, 31st DECEMBER, 1942.

LIABILITIES.

	£ s. d.	£ s. d.	£ s. d.
Capital Value representing Market value of £3,000 3½% Conversion Loan at 21st September, 1926, when Fund was inaugurated		2,220 0 0	
Income and Expenditure Account:—			
Balance as at 1st January, 1941	574 10 1		
Add Excess of Income over Expenditure for the year to 31st December, 1942 ...	121 15 4		
		696 5 5	
			2,916 5 5
			£2,916 5 5

ASSETS.

	£ s. d.	£ s. d.	£ s. d.
£3,452 15*s.* 7*d.* 3½% Conversion Loan (at cost)		2,670 0 0	
Cash at Bank:—			
On Current Account ...	187 7 2		
Post Office Savings Bank Account	58 18 3		
		246 5 5	
			2,916 5 5
			£2,916 5 5

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1942.

INCOME.

	£ s. d.
Interest on 3½% Conversion Loan	120 16 10
Interest on Deposit	1 8 6
	£122 5 4

EXPENDITURE.

	£ s. d.
Sundry Payment	10 0
Excess of Income over Expenditure for the year	121 15 4
	£122 5 4

ANDREW CARNEGIE RESEARCH FUND.

BALANCE SHEET, 31st DECEMBER, 1942.

LIABILITIES.	£ s. d.	£ s. d.	£ s. d.
Sundry Creditors :—			
Grants		100 0 0	
Auditors' Fees		10 10 0	
			110 10 0
Amount due by General Fund			136 0 0
Amount of Original Fund ($100,000) ...		21,241 5 6	
Add Amounts since Capitalised per last Balance Sheet	2,912 9 6		
,, Profits on sales of Investments :—			
£2560 4*s.* 0*d.* India 3%	791 14 3		
£2300 0*s.* 0*d.* India 3½%	736 9 3		
		4,440 13 0	
		25,681 18 6	
,, Surplus Income as at 1st January, 1942 ...	3,351 5 2		
,, Excess of Income over Expenditure for the year	844 16 10		
		4,196 2 0	
			29,878 0 6
			£30,124 10 6

ASSETS.	£ s. d.	£ s. d.
Investments at Cost per Schedule		28,688 0 5
(The Market value of these Investments at 31st December, 1942, was £34,461 10*s.* 8*d.*)		
Cash at Bank :—		
On Current Account	367 9 8	
On Deposit Account	454 8 5	
Post Office Savings Bank Account	389 8 7	
		1,211 6 8
Income Tax Recoverable		225 3 5
		£30,124 10 6

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1942.

INCOME.	£ s. d.
Interest on Investments (Gross)	1,194 7 4
Interest on Deposit	10 6 5
	£1,204 13 9

EXPENDITURE.	£ s. d.	£ s. d.
Scholarship Grants	300 0 0	
Less Grants not taken up	150 0 0	
		150 0 0
Printing Reports		49 6 11
Contribution to General Fund on account of Salaries		150 0 0
Audit Fee		10 10 0
Balance, being excess of Income over Expenditure for the year		844 16 10
		£1,204 13 9

THE IRON AND STEEL INSTITUTE.

SCHEDULE OF INVESTMENTS AT 31st DECEMBER, 1942.

SHOWING NOMINAL VALUES, COST VALUES AND PRESENT MARKET VALUES.

GENERAL FUND OF THE INSTITUTE.

Nominal Value. £ s. d.	Nature of Security.	Market Value, 31st December, 1942. £ s. d.	Cost Value. £ s. d.
2,197 7 0	3½% War Stock ...	2,307 4 4	2,161 0 8
1,324 7 4	3½% Conversion Loan ...	1,370 8 4	1,253 14 0
447 0 0	Southern Railway 4% Debenture Stock ...	484 19 11	449 2 4
1,872 0 0	London and North Eastern Railway 4% 2nd Guaranteed Stock ...	1,675 8 10	2,149 13 3
2,241 0 0	Do. do. 4% 1st do. ...	2,196 3 7	2,431 14 5
2,649 4 0	2½% Consolidated Stock ...	2,185 5 10	1,800 0 0
1,500 0 0	Buenos Ayres Great Southern Railway 4% Debenture Stock ...	922 10 0	1,594 12 9
2,954 1 0	4% Consolidated Stock ...	3,315 18 5	3,175 18 1
437 0 0	London & North Eastern Railway 3% Debenture Stock ...	362 14 2	376 12 5
12,242 19 3	4% Funding Loan 1960/90 ...	13,926 7 5	9,512 7 5
1,000 0 0	3% Defence Bonds (Post Office Register) ...	1,020 0 0	1,000 0 0
2,000 0 0	3% Savings Bonds 1955/65 ...	2,025 0 0	2,000 0 0
		£31,792 0 10	£27,904 15 4

LIFE COMPOSITION FUND.

Nominal Value. £ s. d.	Nature of Security.	Market Value, 31st December, 1942. £ s. d.	Cost Value. £ s. d.
587 13 10	3½% Conversion Loan ...	607 13 9	513 2 3
93 11 10	3% Local Loans ...	91 0 4	84 0 0
1,330 0 0	London & North Eastern Railway 3% Debenture Stock ...	1,103 18 0	1,254 17 6
594 0 0	London Passenger Transport Board 4½% "A" Stock ...	703 17 10	638 6 1
205 15 6	3½% War Loan ...	216 1 3	211 8 10
681 13 0	4% Funding Loan 1969/90 ...	775 7 6	600 0 0
		£3,497 18 8	£3,301 14 8

Nominal Value.	Nature of Security.	Market Value, 31st December, 1942.	Cost Value.
ANDREW CARNEGIE RESEARCH FUND.			
	(Trustees: Sir Wm. Larke, K.B.E., James Henderson, The Hon. R. G. Lyttelton.)		
£ s. d.		£ s. d.	£ s. d.
6,897 14 11	3½% War Stock	7,242 12 8	6,895 16 6
800 0 0	Do.	840 0 0	794 2 0
2,693 12 0	3½% Conversion Loan	2,787 7 7	2,006 19 0
2,642 12 0	3% Local Loans	2,569 18 7	2,527 5 4
2,250 0 0	North Eastern Electric Supply Company 3½% Consolidated Debenture Stock	2,227 10 0	2,261 10 0
1,500 0 0	Great Western Railway 4% Debenture Stock	1,755 0 0	1,204 5 3
2,000 0 0	London Midland & Scottish Railway 4% Debenture Stock	2,140 0 0	1,693 0 6
1,312 0 0	London & North Eastern Railway 4% 1st Guaranteed Stock	1,285 15 2	880 11 11
5,000 0 0	Do. do. 4% Debenture Stock	5,300 0 0	3,540 8 5
6,000 0 0	Do. do. 3% do.	4,980 0 0	3,545 9 3
1,000 0 0	3% Savings Bonds 1955/65	1,012 10 0	1,000 0 0
2,813 2 7	2½% Consolidated Stock	2,320 16 8	2,338 12 3
		£34,461 10 8	£28,688 0 5
WILLIAMS PRIZE FUND.			
	(Trustees: Sir Wm. Larke, K.B.E., James Henderson, The Hon. R. G. Lyttelton.)		
3,452 15 7	3½% Conversion Loan	£3,572 19 8	£2,670 0 0
BESSEMER MEDAL FUND.			
	(Trustees: Lord Airedale and Sir Francis Samuelson.)		
400 0 0	London Midland & Scottish Railway 4% Debenture Stock	£428 0 0	

(*Signed*) R. Lyttelton,
Hon. Treasurer.

(*Signed*) K. Headlam-Morley,
Secretary.

We have examined the foregoing Balance Sheets and Income and Expenditure Accounts with the Books and Vouchers of the Institute and certify them to be correct. We have also verified the Balances at the Bankers and the Securities for the Investments shown above.

224 Regent Street,
London, W.1.
March, 1943

(*Signed*) W. B. Keen & Co.
Chartered Accountants.

THE DESIRABILITY OF REMOVING SULPHUR FROM GASEOUS FUELS FOR HEATING FERROUS METAL.[1]

By A. PREECE, M.Sc. (Leeds University).

Paper No. 10/1943 *of the Alloy Steels Research Committee.*

Summary.

The results obtained in a general study of the high-temperature oxidation of steels are considered with special reference to the harmful effects of the sulphur content of the furnace atmosphere. There is an important difference in the mechanism of scale formation when the furnace temperature exceeds approximately 900° C.; thus, in dealing with industrial heating operations two temperature ranges have to be considered. The results have also shown how the harmful effects of the sulphur dioxide are influenced by the composition of both the steel and the furnace atmosphere. The advantages which result from partial removal of sulphur from the fuel and the working conditions necessary for the full realisation of these advantages are indicated.

Introduction.

Water-gas plants and small producers are being installed in steelworks as reserve units to ensure a supply of gaseous fuel in the event of a temporary failure of the normal gas supplies. These small units are also being used where the town's gas supply is inadequate to meet the increased demand for war production. The auxiliary equipment for the removal of sulphur from the gas produced in these units represents a high proportion of the total cost of the plant, and the following report was drawn up in answer to an enquiry as to how far sulphur removal from gaseous fuel to be used for heating steels was advisable or necessary.

The information contained in this paper has been obtained in a general study of high-temperature oxidation of plain carbon and alloy steels carried out at Leeds University with the aid of financial support from the Alloy Steels Research Committee.

General Considerations.

The following considerations will apply only in furnaces where the products of combustion of the fuel constitute the furnace atmosphere and are in contact with the heated metal.

(1) It has been found that the addition of sulphur dioxide to

[1] Received January 16, 1943. This paper is published by authority of the Alloy Steels Research Committee. The views expressed in it are the author's, and are not necessarily endorsed by the Committee as a body.

typical furnace atmospheres has a profound influence on the scaling characteristics of heated steels. There is usually an important increase in the rate of oxidation with the formation of iron sulphide in the oxide scale.

(2) At tempering and hardening temperatures, *i.e.*, 650° C. to slightly below 900° C., there is no formation of the oxide-sulphide complex; the iron sulphide is distributed as separate particles throughout the scale layer and there is little or no tendency for sulphide penetration along the crystal boundaries.

(3) At temperatures above 900° C. the sulphide forms a molten oxide-sulphide complex at the scale-metal interface, which penetrates into the metal along the grain boundaries. There is also a change in both the scale produced and its adherence to the metal surface, which may affect the ease of scale removal. It will be appreciated, therefore, that the effect of the sulphur dioxide will vary according to whether the furnace temperature is above or below approximately 900° C.

(4) The presence of free oxygen in the furnace atmosphere is important, in that it minimises the evil effects of sulphur dioxide by preventing the formation of iron sulphide in the scale. It should be stressed, however, that oxygen itself accelerates scale formation in all but high-sulphur-containing atmospheres—hence the presence of oxygen is permissible only if the furnace atmosphere already contains appreciable quantities of sulphur dioxide.

(5) Without a knowledge of the design of the particular furnace in which the steel is to be heated, it is wrong to assume that if excess air is used in the combustion of the fuel, the furnace atmosphere in contact with all the steel will contain free oxygen. In furnaces of the semi-muffle type and those in which gas and air premixers are used this assumption is undoubtedly true, but if the gas and air enter the furnace chamber through separate flues there may be regions in the vicinity of the gas ports where combustion is incomplete, and steel in these regions would be scaled under conditions where the sulphur would exert its maximum influence.

(6) The rate of oxidation of steel increases exponentially with temperature; hence, temperature control is important, particularly where the furnace temperature approaches the melting point of the oxide scale. When this temperature is reached there is a sudden increase in the rate of scale formation owing to the removal of the partially protective layer of scale as it melts and flows away from the surface of the metal. Indeed, in this region temperature control is perhaps the most important factor governing oxidation, and much of the advantages resulting from sulphur cleaning, atmosphere control, &c., would be lost if at the same time adequate attention was not given to temperature control.

(7) The compositions of the furnace atmospheres obtained by the complete combustion of typical gaseous fuels are shown in Table I.

Table I.—*Furnace Atmospheres produced by Complete Combustion of Typical Gaseous Fuels.*

	Products of Complete Combustion.			
	CO_2. %.	H_2O. %.	N_2. %.	SO_2. %.
Crude coke-oven gas, 600 grains of sulphur per 100 cu. ft. . .	10	20	70	0·20
Town's gas, 20 grains of sulphur per 100 cu. ft.	10	20	70	0·007
Producer gas from coal containing 2% of sulphur . . .	17	10	74	0·13
Water gas from coke containing 1% of sulphur	16	20	64	0·05

Main Factors influencing the Oxidation of Steel.

A general idea of the relative importance of each constituent of a typical furnace atmosphere may be obtained from the following results found by heating steel specimens for 1½ hr. at 1150° C. Taking a furnace atmosphere consisting of 10% of CO_2, 10% of H_2O and 80% of nitrogen as a basis, then :

Increasing the CO_2 to 20% decreased the oxidation by 35%.
Increasing the H_2O to 20% increased the oxidation by 15%.
Adding 0·2% of SO_2 to the above atmosphere increased the oxidation rate 3 times.
Adding 4% of oxygen or more to the above atmosphere increased the oxidation rate 2½ times.

It will be realised, therefore, that the important factors governing the oxidation of steel are: (*a*) Temperature and (*b*) composition of the furnace atmosphere, particularly with regard to the sulphur dioxide and oxygen contents; and to these must be added (*c*) the presence of certain alloying elements in the steel.

The Heating of Steels in Furnace Atmospheres.

It will be convenient to consider two temperature ranges, *i.e.*, above and below 900° C. Above this temperature the oxide-sulphide complex which forms in the scale causes intense inter-crystalline penetration, which is not so marked at lower temperatures.

(a) *Furnace Temperatures below* 900° *C.*

In this lower temperature range the presence of sulphur dioxide causes an important increase in the rate of scale formation in atmospheres free from oxygen.

In Table II. the increased scaling losses to be expected in changing over from purified to a crude gaseous fuel are shown. Actual scaling losses are given in the second column.

The figures given in Table II. refer only to oxygen-free atmospheres. This is stressed, because oxygen itself causes a rapid increase in scale formation and at the same time renders the sulphur dioxide ineffective as a scaling agent. Oxygen also prevents the formation of iron sulphide in the scale.

It will be clear, therefore, that sulphur removal will result in minimum scaling only in oxygen-free furnace atmospheres. This

TABLE II.—*Increased Scaling Losses on Changing from Purified to Crude Gaseous Fuel. Temperature below* 900° *C.*

Information contained in this Table has been taken from a thesis presented by Dr. E. Simister to Leeds University for the Ph.D. Degree.

Steel exposed 1¼ hr. at 850° C.	Metal lost by Oxidation in Oxygen-Free Furnace Atmospheres (10% CO_2, 10% H_2O, 80% N_2) containing 0·015% of SO_2. Oz. per sq. ft.	Increase in Scaling Losses on Changing from Purified to Crude Gas giving High Concentration of Sulphur Dioxide.		
		0·05% SO_2.	0·10% SO_2.	0·20% SO_2.
		Increased by Factor of—		
Plain carbon steel	0·57	2½	4	5½
1·5% Mn steel	0·56	2	3	4
5% Ni steel	0·33	3	5½	10
3·5% Ni, 0·75% Cr steel	0·50	2½	3	5
4% Si steel	0·44	2	2	2
12% Cr steel	Scale irregular.	2 approx.	2 approx.	2 approx.

may be further illustrated by consideration of the following example. It was found that with a plain carbon steel at 850° C. the addition of 0·10% of SO_2 to an oxygen-free furnace atmosphere caused the same increase in the rate of scale formation as the addition of 2·0% of oxygen; thus, if the working conditions were such that the furnace atmosphere would contain 0·10% of SO_2, it would be advisable to burn the fuel so as to have 2% of oxygen present, because the scaling losses would be the same, there would be little or no sulphide formed in the scale and, further, the scale would be less adherent. If the sulphur dioxide content of the furnace atmosphere were greater than 0·1%, then the presence of the oxygen would maintain a lower rate of scale formation than would otherwise occur.

In this low-temperature range there is a formation of sulphide particles in the scale, but with the plain carbon and 1·5% manganese steel there was no evidence of intercrystalline penetration of scale or sulphide into the metal, even in atmospheres containing as much as 0·2% of SO_2.

With the 5% nickel steel, however, when the concentration of the sulphur dioxide approached 0·05% a slight degree of sulphide penetration occurred, which became more pronounced as the

sulphur dioxide concentration was further increased; in a high-sulphur atmosphere (80% N_2, 10% CO_2, 10% H_2O plus 0·2% SO_2), after 8 hr. heating at 850° C. this intercrystalline penetration extended 0·002 in. into the metal, but when 3% of oxygen was also present there was no penetration of scale. With nickel steels, therefore, the presence of free oxygen is essential if the furnace atmosphere contains sulphur.

The 3·5% nickel, 0·75% chromium steel and the 12% chromium steel also showed slight evidence of intercrystalline penetration when the sulphur dioxide content of the atmosphere reached 0·05%. When oxygen was added to the furnace atmosphere sulphide penetration was prevented, but with the nickel-chromium steel an equally deep intercrystalline penetration of oxide occurred, which might be as troublesome as the sulphide penetration as far as scale removal is concerned.

The high resistance of the 4% silicon steel to oxidation was destroyed by sulphur dioxide, and although the increased scaling was not accompanied by intercrystalline penetration of scale into the metal a subscale formation occurred at the scale-metal interface which would be difficult to remove by the normal descaling processes and would undoubtedly result in a poor surface finish.

The more highly alloyed steels, such as the 18% chromium, 2½% nickel steel, higher-chromium steels and an 8% aluminium steel, showed very slight attack when exposed to furnace atmospheres containing as much as 0·2% of SO_2. A thin skin of protective oxide formed on the surface, which prevented further oxidation.

(b) *Furnace Atmospheres above* 900° *C.*

The effectiveness of sulphur dioxide in increasing the rate of scale formation becomes greater as the furnace temperature is raised, and at forging temperatures the loss of metal due to oxidation represents an appreciable tonnage of steel. In addition, at temperatures above 900° C. this increased scaling in sulphur-containing atmospheres is accompanied in certain circumstances by deep intercrystalline penetration into the steel of the iron-sulphide/iron-oxide complex which is formed at the scale-metal interface.

Table III. has been drawn up in a similar manner to Table II., and shows the increase in scaling losses to be expected on changing over from a purified to a crude gaseous fuel when burnt to give no free oxygen in the products of combustion. It will be noted that the scaling losses are high even when using a purified gas and that they are further increased when sulphur is present.

In considering the behaviour of the four resistant steels in Table III., where continued oxidation had been prevented by the formation of an extremely thin chromium-rich oxide skin, the conditions of test should be emphasised, *i.e.*, 1½ hr. at a constant temperature of 1150° C., since it is not known to what extent this

TABLE III.—*Increased Scaling Losses on Changing from Purified to Crude Gaseous Fuel. Temperature above 900° C.*

Information contained in this Table has been taken from a thesis presented by Dr. R. V. Riley to Leeds University for the Ph.D. Degree.

Steel exposed $1\frac{1}{2}$ hr. at 1150° C.	Metal lost by Oxidation in Oxygen-Free Furnace Atmosphere (10% CO_2, 10% H_2O, 80% N_2) containing 0·015% of SO_2. Oz. per sq. ft.	Increase in Scaling Losses in Changing from Purified to Crude Gas giving Higher Concentration of SO_2 in Furnace Atmosphere obtained by Complete Combustion of Gas.		
		0·05% SO_2.	0·10% SO_2.	0·20% SO_2.
		Increased by Factor of—		
Plain carbon steel	5·5	$1\frac{1}{2}$	2	3
5% Ni steel	3·2	$1\frac{1}{2}$	2	4
3·5% Ni, 0·75% Cr steel	3·3	$1\frac{1}{2}$	2	3
4% Si steel	4·7	$2\frac{1}{2}$	3	$3\frac{1}{2}$
3% Si, 9% Cr steel	6·6	$1\frac{1}{2}$	2	$2\frac{1}{2}$
13% Mn steel	3·1	2	3	$4\frac{1}{2}$
12% Cr steel	6	$1\frac{3}{4}$	2	$2\frac{1}{2}$
18% Cr, 2·5% Ni steel	4	$1\frac{1}{3}$	$2\frac{1}{2}$	3
18% Cr, 8% Ni steel	approx. 2 approx.	approx. $1\frac{1}{4}$ approx.	approx. $1\frac{3}{4}$ approx.	approx. 4 approx.
25% Cr, 17% Ni steel; 30% Cr steel; 25% Cr, 7% Ni, 4% W steel	A protective oxide skin formed which prevented further oxidation even when 0·2% of SO_2 was present.			
8% Al steel	An alumina-rich film which formed in sulphur-free atmospheres was destroyed by SO_2 and rapid scaling occurred.			

high degree of resistance would be retained over long periods of exposure or with fluctuating temperatures. Experiments along these lines are in progress at the present time.

The increased scaling due to sulphur dioxide in oxygen-free furnace atmospheres was accompanied in this higher-temperature range by intense intercrystalline penetration of the oxide-sulphide complex, with the plain carbon, the 13% manganese, the 3·5% nickel, 0·75% chromium and the 5% nickel steel. Penetration was most severe with the 5% nickel steel, in which it had extended to a depth of 0·02 in. after $1\frac{1}{2}$ hr. heating at 1150° C. in a high-sulphur atmosphere containing 0·2% of SO_2. This degree of penetration would undoubtedly give trouble in forging operations.

No evidence of intercrystalline penetration was found in the 4% silicon, the 3% silicon, 9% chromium and the 12% and higher chromium steels; sulphide particles were found in the inner layers of the scale, but their only effect seemed to be to produce a more even scale-metal interface.

No oxide-sulphide complex could be found in the scale formed at 1000° or 1150° C. in furnace atmospheres containing less than

0·03% of SO_2; hence there would appear to be little advantage in taking sulphur removal beyond the stage which would give less than 0·03% of SO_2 in the furnace atmosphere, particularly as the cost of sulphur removal increases rapidly as the sulphur content of the fuel becomes less.

Having established a permissible sulphur content in the furnace atmosphere, it is possible to calculate the corresponding sulphur value of the gaseous fuel and so determine the amount of sulphur to be removed from the latter. This has been done for each of the three gaseous fuels, and the results are given in Table IV.

One interesting feature of Table IV. is the comparatively small amount of sulphur to be removed from producer and water gas, and, while iron-oxide cleaning plants can be designed for this purpose, a cheaper method may be found by using ammonia washing towers.

TABLE IV.—*Sulphur to be Removed from Gaseous Fuels.*

Fuel.	Ratio of Gas to Air for Complete Combustion.	Critical Sulphur Content of Fuel to give 0·03% of SO_2 in Products of Complete Combustion.	Sulphur to be Removed.
		Grains per 100 cu. ft.	
Crude town gas, 600 grains of sulphur per 100 cu. ft.	1 : 4	90	510
Water gas from coke containing 1% of sulphur (= 108 grains per 100 cu. ft.)	1 : 1·75	50	58
Water gas from coke containing 2% of sulphur (= 254 grains per 100 cu. ft.)	1 : 1·75	50	204
Producer gas from coal containing 2% of sulphur (= 230 grains per 100 cu. ft.)	1 : 1	39	190
Producer gas from coke containing 1% of sulphur (= 100 grains per 100 cu. ft.)	1 : 0·8	32	68

The statement that oxygen added to furnace atmospheres imposes its own influence on the rate of scale formation and renders the sulphur dioxide ineffective is true at forging temperatures, but needs some qualification in the case of a few steels, *e.g.*, with the plain carbon, 13% manganese and 4% silicon steels, the addition of 1–2% of oxygen to the furnace atmosphere containing sulphur dioxide accentuated the accelerating influence of the sulphur dioxide, and it was only with higher oxygen additions that the sulphur dioxide became ineffective. The silico-chromium steel is also an exception, in that the influence of sulphur dioxide and oxygen when present together is roughly the sum of their separate effects.

Experiments have shown that sulphur dioxide maintains its accelerating influence on scale formation up to 1330° C., and, with steels containing silicon, as this temperature is approached the effect of any oxygen which may be present, instead of replacing the effect of the sulphur dioxide, tends to augment it. No precise information is available for temperatures above 1330° C.

Apart from its effect on the scaling losses, the presence of oxygen in furnace atmospheres containing sulphur dioxide suppresses the formation of the oxide-sulphide complex in the scale and prevents intercrystalline penetration of the latter into the steel.

Conclusions.

(1) The effect of sulphur-bearing gases in furnace atmospheres is two-fold, (i) an increase in metal loss due to scaling, and (ii) intergranular penetration of scale.

(2) Both effects are pronounced at temperatures above 900° C., the first being important economically and the second inimical to good forging properties.

(3) For temperatures above 900° C., sulphur removal is considered essential, but its value is not fully realised unless combustion is so controlled as to avoid the presence of free oxygen in the furnace atmosphere.

(4) For temperatures below 900° C., the loss of metal due to scale formation is not excessive even with unpurified gas; hence, sulphur removal is not considered essential in this temperature range, except for certain nickel-bearing steels in which intergranular penetration of the oxide may be caused by the presence of sulphur.

(5) Intergranular penetration of oxide-sulphide scale has not been found when the concentration of sulphur dioxide in the furnace atmosphere is reduced to 0·03%; thus, only partial sulphur removal is then called for.

(6) The presence of free oxygen in the furnace atmosphere, although it gives a high rate of scale formation, counteracts the effects of sulphur dioxide and produces a non-adherent type of scale.

Acknowledgments.

The author wishes to express his thanks to Members of the Alloy Steels Research Committee for their helpful discussions. He would also thank Mr. A. Hartley, of Leeds University, and Mr. N. Williams, of Messrs. Humphrey and Glasgow, Ltd., for their assistance in confirming certain results contained in the paper.

A REVIEW OF THE WORK OF THE INGOT MOULDS SUB-COMMITTEE.[1]

By R. H. MYERS (The British Iron and Steel Federation, London), Chairman of the Ingot Moulds Sub-Committee.

Paper No. 19/1943 *of the Committee on the Heterogeneity of Steel Ingots* (*submitted by the Ingot Moulds Sub-Committee*).

Abstract.

As the result of experimental work and of statistical studies, it is clearly shown that great economy in ingot-mould material can be obtained very simply by reduced casting-to-stripping time, by attention to wall thickness and composition, and by improved lay-out, equipment and practice in the casting pit.

Foreword.

This review presents an account of the work of the Ingot Moulds Sub-Committee and includes, in addition to that already published, some unpublished work as well as work in progress or contemplated.

The various aspects of the work are listed below and it will be convenient to discuss them in this order :

SECTION I.—The Behaviour of Ingot Moulds in Service.—Statistical Investigation of Performance and Large-Scale Experiment.

Part A.—*Factors having an Influence on Ingot-Mould Life.*
" B.—*Standard Method of Recording Mould History* (*Initiated by Questionnaire*).
" C.—*Correlation of Collective Data.*
" D.—*Analysis of Collective Data by Graphical Methods.*
" E.—*Individual Works Investigations* (*Statistical Examination of Records and Practical Experiments*).
" F.—*Modes of Failure of Ingot Moulds.*
" G.—*Other Work.*

SECTION II.—The Basic Causes of Cracking.

Part A.—*The Determination of the Temperature Gradients in the Wall of a Slab Mould.*
" B.—*Papers Presented for Publication through the Stresses in Moulds Panel.*
" C.—*Laboratory Work.*
" D.—*A Technique for Determining the Temperature in the Interior of a Freezing Ingot.*

As far as is possible the views expressed by the Sub-Committee in previous publications have been retained, but in the light of more

[1] A Joint Sub-Committee of the Open-Hearth Committee of The Iron and Steel Industrial Research Council and the Committee on the Heterogeneity of Steel Ingots (a Joint Committee of The Iron and Steel Institute and The British Iron and Steel Federation reporting to The Iron and Steel Industrial Research Council). MS. received December 24, 1942.

recent information some of the results discussed earlier are here shown, in certain instances, to have a somewhat wider significance.

SECTION I.—The Behaviour of Ingot Moulds in Service.—Statistical Investigation of Performance and Large-Scale Experiment.

Part A.—*Factors having an Influence on Ingot-Mould Life.*

At the outset a comprehensive list of some forty-seven factors believed to have an influence on mould life was prepared. The list included factors associated with both manufacture and use of moulds.[1]

Although the influence of the individual factors could not be expressed quantitatively, it was known by experience in some cases and believed in others that certain factors were of major importance as regards their influence on mould life. The chief concern, therefore, of the Sub-Committee was to make a selection of the more important factors and to investigate the influence of each one separately. Those which come within the scope of this review are listed below:—

Factors Associated with Manufacture.

(1) Design.
- (i) Wall thickness.
- (ii) Abrupt changes in wall thickness.
- (iii) Whether small- or large-end-up, open or solid-bottom.

(2) Cupola charge mixtures.
- (i) Brands of pig iron used.
- (ii) Proportion of steel and mould scrap used.

(3) Chemical composition.
- (i) Carbon.
- (ii) Silicon.
- (iii) Manganese.
- (iv) Sulphur.
- (v) Phosphorus.
- (vi) Chromium.

(4) Founding technique.
- (i) Casting temperature (fluidity)
- (ii) Lapse of time between casting and removal from the sand.
- (iii) Whether annealed or otherwise before use.
- (iv) Period of weathering before use.

(5) Physical and Mechanical Properties.
- (i) Structure, particularly with regard to graphite.
- (ii) Strength at room and at elevated temperatures.
- (iii) Thermal expansion.
- (iv) Thermal conductivity.

Factors Associated with Usage.

(1) Steel.
- (i) Temperature.
- (ii) High or low carbon content.

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[1] Seventh Report on the Heterogeneity of Steel Ingots, *Iron and Steel Institute*, 1937, *Special Report No.* 16, pp. 146–147.

(2) Method of casting.
- (i) Direct.
- (ii) Tundished.
- (iii) Bottom-cast.
- (iv) Floor-, pit- or car-cast.
- (v) With or without feeder-heads.

(3) Method of stripping.
- (i) Mechanical stripper.
- (ii) Overhead crane.
- (iii) Steam jib crane.

(4) Temperature of mould when casting steel, depending on :
- (i) Frequency of use of mould.
- (ii) Cooling conditions.

(5) Temperature of mould reached before stripping, depending on :
- (i) Casting-to-stripping time.
- (ii) Space between moulds when set.
- (iii) Whether teemed in open or confined space, *e.g.*, sunk pit.

Part B.—*Standard Method of Recording Mould History (Initiated by Questionnaire).*

The object was to determine the relative importance of the above factors by the co-ordination of works data or by practical experiment. It was realised that if any serious attempt was to be made to ensure comparable results, data would have to be expressed and experiments conducted on a common basis. As a first step towards this end, a questionnaire, based on the above factors, was prepared and circulated to all steelmakers (some of whom were also makers of moulds) but not to mould-makers as such. Thereafter a standard form for recording mould history (based on existing methods) was prepared by the Sub-Committee; a reproduction is given on the next page. This, together with a system in daily use by a member firm, was published in the Seventh Ingot Report, pp. 160–162. It was hoped that these methods would be generally adopted as standard (at least by the high-production steel plants) where the actual consumption of mould material (representing relatively few types in constant use) was very substantial.

The justification for adopting such a system of mould recording is clearly demonstrated in the following Parts C to E.

Part C.—*Correlation of Collective Data.*

Altogether data relating to some forty-five types of moulds were submitted in answer to the questionnaire. These were subsequently examined. The data appear in tabular form in the Seventh Ingot Report, pp. 168–183.

(1) *Life of Different Types of Moulds.*

Wide differences in mould life were noted between different types of moulds. This was not due to design as such (except perhaps in isolated cases) but to the treatment in service to which a particular design or type of mould was subjected.

A Standard Card for Recording Ingot Mould History.

DEVISED BY THE INGOT MOULDS SUB-COMMITTEE.

FIRM :—

DESCRIPTION OF MOULD.
- Works drawing No. ....
- Nominal capacity ....
- Weight of mould..
- Type ....

DETAILS OF MANUFACTURE.

MAKER'S NAME ....

DISTINGUISHING MARK ....

	Date.	Time.
CAST AT FOUNDRY	....	....
STRIPPED AT FOUNDRY	....	....

TEMPERATURE OF METAL. From cupola ....° C. / From ladle ....° C. — Instrument used ....

TIME TAKEN TO CAST. (Min.)..

MIXTURE.
- Scrap: Steel ....%
- Scrap: Iron ....%
- Brand of iron. 1. ....%
- 2. ....%
- 3. ....%
- 4. ....%

ADDITIONS. Cupola ....
Ladle ....

MOULD ANALYSIS.	T.C.	Gr.C.	Si.	Mn.	S.	P.	Other Constituents.
Sample							
Scrapped mould							

	Top.	Bottom.
MINIMUM THICKNESS OF MOULD WALL (Actual) (In.)	....	....

DRESSING. Core ....
Mould before use ....

REMARKS ....

DETAILS OF SERVICE.

DATE PUT INTO SERVICE .... LIFE ....

DATE SCRAPPED .... FAILURE DUE TO....................

AVERAGE WEIGHT OF INGOT
- Chill weight ....
- Total weight ....

TYPE OF FEEDER HEAD (if any)..

AVERAGE TEEMING SPEED ....

AVERAGE TIME BETWEEN TEEMING AND STRIPPING ....

NORMAL TEMP. OF MOULD WHEN CASTING ....

MOULD DRESSING ....

STEEL QUALITY ....

TOP-POURED.......................% BOTTOM-POURED.......................%

ANY MACHINING (indicated on drawing) ....

Submit photographs in abnormal cases
- (1) showing general condition of mould surface.
- (2) macrograph of cross-section (natural size).
- (3) micrograph of cross-section, × 3, showing decarburisation of working face.

The small-end-up type showed an average of 83 lives as against 53 for the wide-end-up solid-bottom and centre-run types.

Whilst the former type was used principally under car-casting and machine-stripping conditions, the latter suffered the disadvantages of pit- or floor-casting, crane-stripping, inversion and in many cases bumping to release the ingot. They also took longer to strip and would tend to be hotter when receiving the next cast. The influence on mould life of these last two factors is dealt with more fully later, but it is noteworthy that precisely the same type of mould has been known to give a life of 98 in one shop where there are car-casting, machine-stripping and air-cooling facilities, as against a life of 56 in another shop where crane-stripping and pit- or floor-casting conditions exist.

(2) *The Effect of the Method of Teeming.*

The average lives of open-end moulds teemed direct and bottom-cast were 74 and 99, respectively.

Tundishing improved the life of moulds, but this effect could not be isolated, because of the deleterious influence of hot tops which were usually present.

Part D.—*Analysis of Collective Data by Graphical Methods.*

(1) *The Effect of the Casting-to-Stripping Time.*

Graphical methods disclosed remarkable possibilities for increasing mould life with decrease in casting-to-stripping time.

The rate of improvement in mould life was shown to increase rapidly the nearer one approached the minimum time practicable. Conversely, mould life was shown to decrease with increase of casting-to-stripping time up to a point where a further increase appeared to have no effect (Fig. 1) (*see also* Seventh Ingot Report, pp. 164–165). Both these aspects have been proved by practical experiment and are mentioned later. Moulds occupying positions outside the band in Fig. 1 were shown to be abnormal or subject to abnormal conditions.

The true significance of decreasing the casting-to-stripping time does not appear to be generally appreciated. *The advantages to be gained justify large expenditure in equipping plants with stripping facilities where at present these are limited owing to plant layout.* With the exception of perhaps one or two specific types of steel, any depreciation in the quality of the ingot by quicker stripping has yet to be proved, once the frozen envelope is sufficiently strong to support the liquid centre, and always provided that the ingot remains in a vertical position until solid throughout. At Hofors in Sweden equipment was installed to strip small high-quality steel ingots in 2–3 min. after casting, with the result that the life of the ingot mould was trebled.

In further support of this statement, Jellinghaus, in discussing

Ristow's paper on ingot moulds,[1] cited a case where the mould life had been increased from 205 to 310 by decreasing the average casting-to-stripping time from 18 min. to 8 min.

Earlier release from the hot ingot reduces the temperature attained by the mould and in turn the tendency to oxidation, growth and crazing of the working face, as well as to premature crack failure; it also renders the mould cooler for subsequent use, thereby making it possible to reduce mould stocks; and, not least important, it permits the delivery of hotter ingots to the soakers.

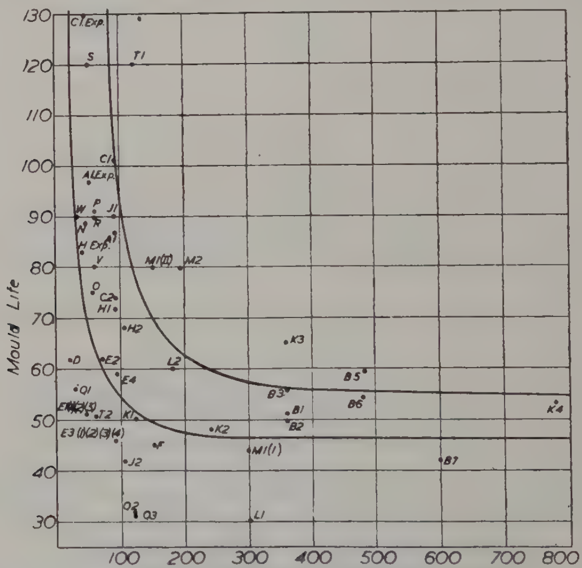

FIG. 1.—Correlation of Mould Life with Lapse of Time between the Casting and Stripping of Ingots.

An example of what can be spent with advantage on plant and equipment to ensure better mould performance is given below. Consider a steelworks producing 250,000 tons of ingots per annum, the cost of ingot moulds being £14 per ton less a scrap value of £6 per ton (*i.e.*, £8 per ton net). Assume that the ratio of mould to ingot weight is 1·0, and that an average mould life of 100 casts can be increased to 130 casts. In the author's belief, a 30% increase is a conservative estimate of what could be achieved in many high-production plants:

Mould life	100 casts	130 casts
Consumption of mould metal per ton of steel .	22·4 lb.	17·2 lb.
Cost of moulds per annum	£20,000	£15,385
Cost of mould metal per ton of steel . .	19·20*d*.	14·77*d*.

[1] *Stahl und Eisen*, 1940, vol. 60, pp. 401–404, 427–433.

By increasing the average mould life from 100 to 130 casts there is therefore a saving of 4·43*d*. per ton of steel, or £4,615 per annum. At an interest rate of 5% this would justify the expenditure of about £92,000 on plant and equipment to secure this extra mould life, to say nothing of the added advantages obtained, such as hotter ingots sent to the soakers, less mould stocks required, &c.

(2) *The Influence of Mould-Wall Thickness.*

A graph of exceptional significance is shown in Fig. 2 (*see also* Seventh Ingot Report, p. 166).

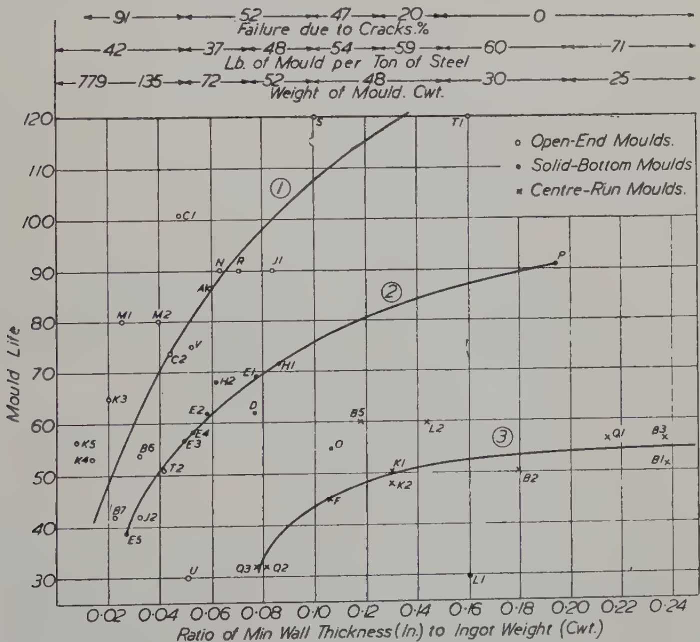

FIG. 2.—Correlation of Mould Life with the Ratio of the Minimum Wall Thickness to the Ingot Weight.

The factor selected for plotting against mould life was the ratio of the minimum wall thickness to the ingot weight. The mould ratio (cross-sectional area of the mould to that of the ingot) when plotted against mould life showed similar, but slightly less definite, relationships.

The graph clearly indicates not only the relationship between the wall thickness and the mould life for three different types of moulds, but also the dependence both of the mode of failure and of the consumption of mould material on the wall thickness as follows :

(i) Thick-walled moulds of high mould ratio give a high life and fail by crazing.

(ii) Thin-walled moulds of low mould ratio give a low life and fail by cracking.

(iii) There is a strong tendency (in the examples given) for the large moulds to crack through having a low mould ratio and for the small moulds to craze through having a high mould ratio.

(iv) At some intermediate mould ratio, where the mode of failure is presumably on the border line between crazing and cracking, minimum consumption of mould material is obtained.

The optimum wall thickness for a given mould capacity will vary with the design and the composition of the mould metal and particularly with the conditions under which the mould is used.

In general, if a mould is failing consistently by crazing, the wall thickness is above the optimum, and steps can be taken to reduce it, with resulting economy in mould material. Conversely, if a mould is failing consistently by cracking, the wall thickness is below the optimum, and thickening the mould wall will again effect economy in mould material.

Cases are on record where considerable economies have been effected through reference to this graph. The wall thickness may be above or below the optimum as a result of a sudden change (beneficial or otherwise) in manufacture or in service, and steps should be taken accordingly. Quicker stripping, for instance, if this were consistent and permanent, would probably permit of a reduction in wall thickness.

There can, therefore, be no general specification of wall thickness for a mould of given capacity, and it devolves on each steel plant to determine this for itself.

Herein lies one of many reasons not merely for adopting a system of recording but for knowing the position at any moment by a periodic scrutiny of data. Most of the following results outlined in Section I., Part E, which have been reported chiefly by one firm in The United Steel Companies group, come within this category, but it must be realised that they are not necessarily of general application nor even may they hold good for the individual works over long periods. Many of the factors involved are interdependent; and making a change in one may necessitate a re-examination of the records to determine the new set of optimum conditions, which may differ from those applicable before the change.

Part E.—*Individual Works Investigations* (*Statistical Examination of Records and Practical Experiments*).

(1) *The Effect of Composition on Mould Life.*

A recent examination by graphical methods of some four hundred moulds enabled the above-mentioned firm to decide upon the

optimum composition (manganese 0·8–1·0%, silicon 1·0%, sulphur 0·06% max., phosphorus 0·10%) for one type of mould in frequent use (Figs. 3, 5, 7 and 8). The moulds were arranged in groups according to increasing contents of the above elements (the number in each group is indicated on the life curve), and, by plotting for each group the average value of mould life, the effect of these elements on the life was observed. The results (not published) were reported at the Seventeenth Open-Hearth Conference and are embodied in the following sub-sections (*a*) to (*d*).

(a) *The Effect of Manganese.*—In the early stages of the work it was shown that as the manganese increased from 0·75 to 1·00%, failure of the mould due to cracking decreased and the life increased.[1]

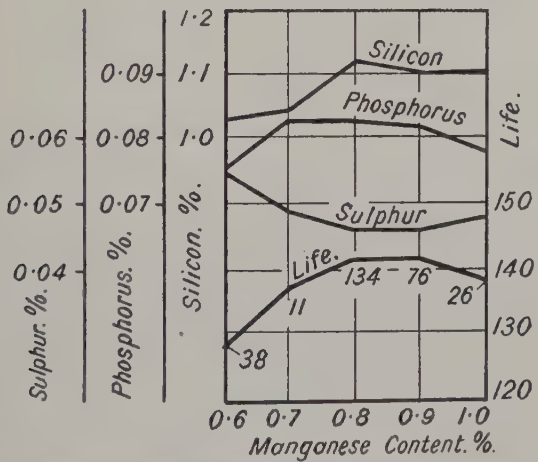

FIG. 3.—Moulds Grouped according to their Manganese Contents.

Unlike silicon, which is a graphitiser, manganese is a carbide stabiliser, and on the above result it would not have been unreasonable to expect higher manganese to induce rather than to reduce cracking. Having in mind, however, the relatively high range of silicon (1·8–2·0%), it can be assumed that any influence of the manganese as a stabiliser has been masked by the high silicon as a graphitiser, and the tendency to reduce cracking is probably the result of additional strength imparted to the material by the manganese. In a later examination of records where a lower silicon content was found to improve life, the optimum manganese was shown to be lower, of the order of 0·9% (Fig. 3). Naturally, the stabilising effect of manganese, with its tendency to reduce crazing, was more marked with the lower silicon, and a lower concentration of manganese was sufficient to produce the same effect.

[1] Seventh Ingot Report, pp. 153–154.

(b) *The Effect of Silicon.*—Within the range 1·70–2·00% of silicon, the mould life was shown to decrease with increase in silicon, *i.e.*, oxidation, growth and crazing were liable to occur at an earlier stage. Conversely, the life increased with decreasing silicon content, despite a greater tendency to crack—rather than to craze-failure.[1]

Later, a similar effect on the life was observed over a wider range of silicon, from about 0·9% to 1·9% (Fig. 4). Below about 0·9%

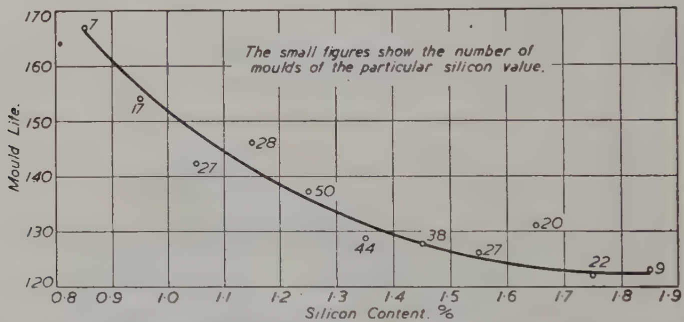

FIG. 4.—22½-in. Semi-Closed-Top Moulds. Effects of silicon content on the life.

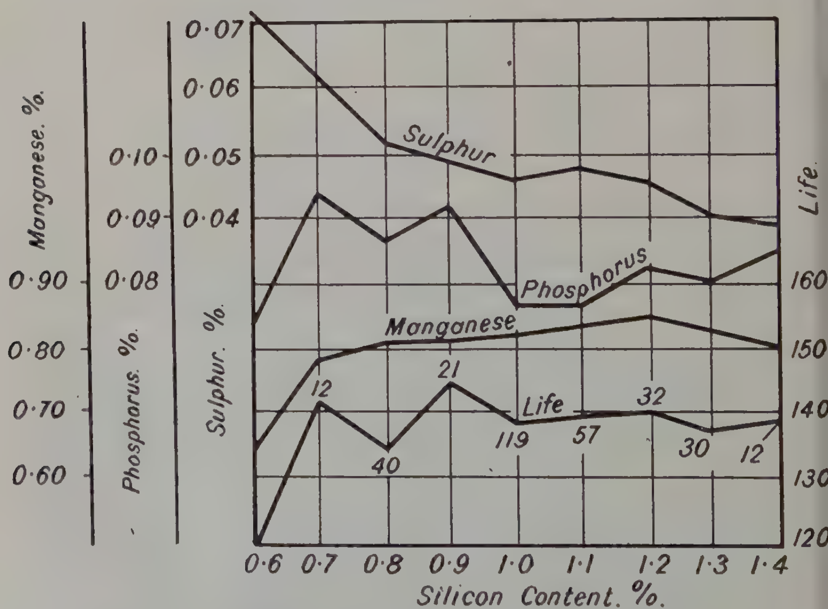

FIG. 5.—Moulds Grouped according to their Silicon Contents.

[1] Seventh Ingot Report, p. 154.

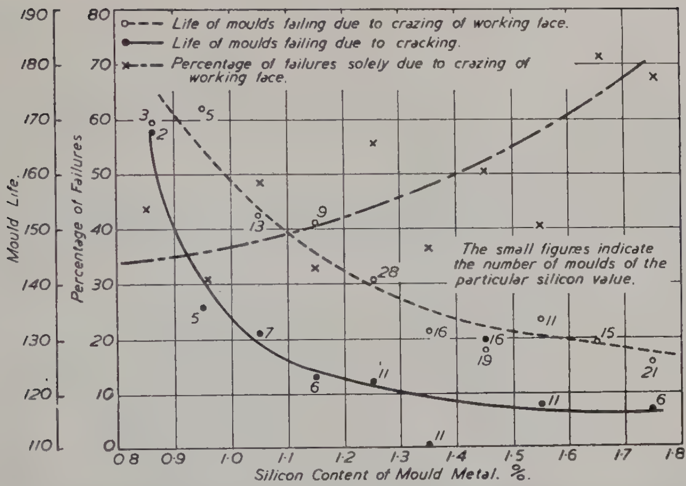

FIG. 6.—22½-in. Semi-Closed-Top Moulds. Effect of silicon content on the mode of failure.

of silicon, however, the life commenced to decrease again, whilst at 0·6% of silicon premature failure by cracking was observed (Fig. 5). Although more moulds failed by crazing the higher the silicon content was, some moulds failed solely by cracking and some solely by crazing at all values of silicon between 0·9 and 1·9%, but for a given silicon content those which failed by crazing gave a higher life than those which failed by cracking (Fig. 6). Those moulds,

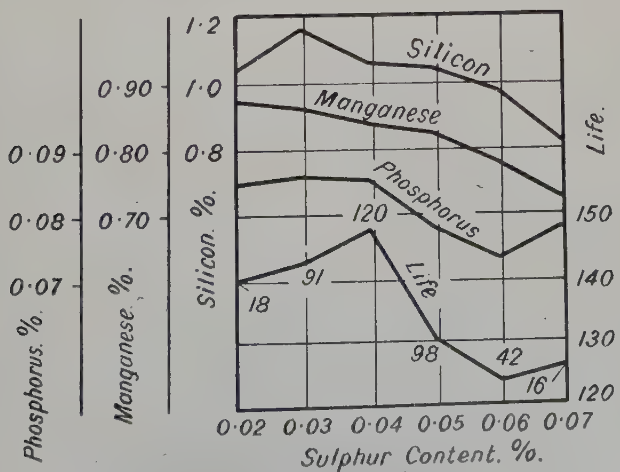

FIG. 7.—Moulds Grouped according to their Sulphur Contents.

however, which showed a tendency to fail by cracking and crazing simultaneously gave the highest life throughout. This is not shown on the graph, but was found on a subsequent examination.

(c) *The Effect of Sulphur.*—The adverse effect of sulphur above 0·045% (Fig. 7) was apparent, but this was not necessarily due to sulphur as such but to poor coke and cold-working of the cupola. This aspect is dealt with later.

(d) *The Effect of Phosphorus.*—The increasing beneficial effect of phosphorus up to 0·1% (the limit of the range examined at the time) was pronounced (Fig. 8). Two moulds since made, having phos-

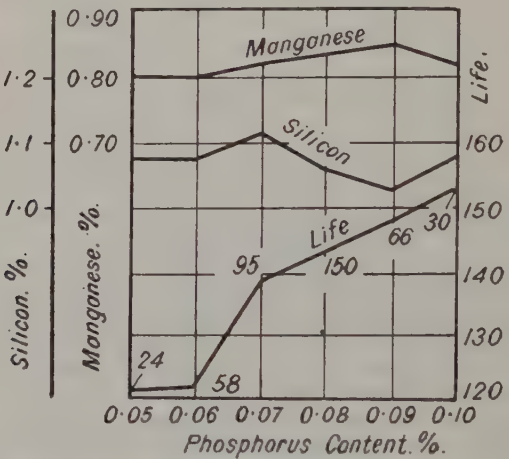

FIG. 8.—Moulds Grouped according to their Phosphorus Contents.

phorus contents of 0·216% and 0·245%, well exceeded the average figure for mould life. Moulds made with more than 0·3% of phosphorus, however, gave lives less than the average and failed prematurely through cracking. Moulds containing 0·17% and 0·24% of phosphorus (mentioned in the Sub-Committee's First Report [1]) gave much improved lives when compared with those with 0·075% of phosphorus.

It would, therefore, seem that for the individual conditions prevailing at this plant it was safe and even beneficial to increase the phosphorus content of mould iron to 0·25%, with the possible exception of large moulds for forge products.

Note.—It is important that high-phosphorus mould scrap should be segregated and clearly marked to prevent it from being remelted for manufacture into large ingot moulds.

(e) *The Effect of Chromium.*—Additions of 0·3% and 0·5% of chromium were made to cupola charges of 100% hematite iron.

[1] Seventh Ingot Report, Section VI.

Compared with moulds made from 100% hematite alone there was some slight improvement in life, but this was more than offset by the increased cost of the mixture.

(2) *The Influence of Foundry Practice.*

The total make of one type of mould for the year was arranged in groups according to the month of manufacture and the average analyses. There was a close relationship between the phosphorus and the life except at one period when the sulphur increased. Subsequent investigation proved that this was not due to sulphur as such, but to indifferent cupola practice, the bad period being associated with poor-quality coke and cold melts. A stricter control of foundry practice was therefore imposed and a system of recording put into effect.

(a) *The Method of Recording in the Foundry.*—The recorded items fall under the following headings:

Charge mixture with analyses of the constituents.
Calculated analyses.
Spoon-test analyses.
Fluxes used.
Tapping times.
Blowing pressure.
Temperature of ladle metal (Schofield pyrometer).
Fluidity of the ladle metal (*see* below).
Serial numbers of the moulds cast.
Remarks.

(b) *A Fluidity Test.*—The fluidity test involved the immersion of a mild-steel rod in the ladle metal for a given time, the loss in weight (expressed as a percentage) being a measure of so-called "fluidity." Actually it would seem to be a measure of fluidity and solvent effect together, both of which are variables dependent upon temperature and composition. The test was one used by Schiffer and Feldmann, who referred to it in a paper on "Pig Iron for Steelmaking and its Relation to the Melting Process in the Steelworks."[1] They found that the "fluidity" as determined by this test increased with (*a*) decreasing silicon, (*b*) increasing manganese, (*c*) increasing phosphorus, and (*d*) increasing temperature.

Since mould life has been found to follow a similar trend it was considered that here was a valuable "yard stick" for judging the suitability of cupola iron for ingot moulds. Subsequent results have proved this.

(c) *Relationship between the Rod and the Spiral Fluidity Tests.*—The relationship between the rod and the notched spiral fluidity test devised by the British Cast Iron Research Association was determined experimentally for the Sub-Committee by the aforementioned firm in co-operation with the B.C.I.R.A. The results indicated that a straight-line relationship existed between the two

[1] *Stahl und Eisen*, 1938, vol. 58, pp. 641–646.

tests. Hence, for routine work the immersion rod test, which is much simpler, can be said to be as reliable a guide as the spiral test.

(d) *The Effect of Various Proportions of Mould and Steel Scrap in the Cupola Charge.*—The lives of a large number of moulds made from (*a*) 100% mould scrap, (*b*) 25% mould scrap, (*c*) 10% mould scrap plus 10% steel scrap, and (*d*) 10% steel scrap were compared with those obtained from moulds made with 100% hematite iron. The results showed little or no difference in mould life. What difference there was was within the scope of experimental error.

(e) *The Effect on Composition of Repeatedly Melting Mould Scrap in the Cupola.*—A graph prepared for the Sub-Committee by the B.C.I.R.A. appears in the Seventeenth Open-Hearth Conference Proceedings. It shows the increase in sulphur and decrease in silicon and manganese which can be expected with ten successive remelts of hematite iron. The sulphur rose steadily from 0·05% to 0·35%. The silicon dropped from 2·0% to just under 1·0%, and the manganese from about 0·8% to 0·3%.

If, however, the cupola charge was diluted with 50% of virgin hematite, the sulphur appeared to reach a maximum of 0·11% on the tenth remelt.

(f) *The Effect of Various Proportions of Different Brands of Hematite, Basic Iron, Mould, Foundry and Steel Scrap.*—The mixture (one of five) giving the best mould life was as follows:

East and West Coast hematite (half and half)	70%
Mould scrap	15%
Basic iron, foundry and steel scrap	15%

The analysis of the mixture was:

Silicon.	Manganese.	Sulphur.	Phosphorus.
1·0%	0·80%	<0·045%	0·095%

The average sulphur of this mixture was low and the phosphorus high compared with the other four mixtures, and these beneficial effects probably masked in some degree the effect of the charge mixture as such.

(g) *The Effect of Part-Blown Hematite Iron from the Converter.*—Four moulds, made from this material, had the following average analysis:

Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
2·38%	2·19%	0·034%	0·033%	0·86%

All four moulds cracked the first time they were put into use.

(h) *The Effect of the Time between Casting the Mould in the Foundry and its Removal from the Sand.*—Three batches of eight moulds each were stripped in the foundry at intervals of 5, 10 and 24 hr. after casting.

Stripping consisted in drawing the core spindle, followed immediately by removing the box. The sand still adhering was left

until cold. All the moulds ran a normal life and failed by crazing. Those stripped in 10 hr. (the normal practice) gave about 10% higher life than the other two groups. No conclusions have as yet been drawn from this test.

A similar test was conducted on moulds stripped normally and others left in the sand throughout the week-end. No difference in mould life was observed between the two methods of treatment.

(i) *The Effect of Annealing.*—Two batches of six moulds, of a type which failed owing to cracking, were annealed. Six were given a stress-relieving anneal at 450° C. for 10 hr. and six were annealed (at 860° C.) for 10 hr. No difference was observed in the life between these and untreated moulds, and all failed in the usual manner owing to longitudinal corner or facial cracks. The effect which detachable feeder-heads have on the mode of failure may have obscured any effect of annealing. The Sub-Committee felt at the time that the result was not conclusive and contemplate carrying out further tests when conditions are more opportune.

(j) *The Effect of Weathering to Reduce Foundry Stresses.*—The lapse of time between casting the mould in the foundry and putting it into service was examined for some six hundred moulds each in two steel plants. The periods varied from under one week to over 16 weeks. The results showed definitely that there was nothing to be gained from the practice of ageing moulds before use.

(3) *The Influence of Casting-Pit Practice.*

(a) *The Effect of Casting-to-Stripping Time.*—A number of experiments in this field were conducted by different firms, and in each case a marked improvement in mould life was observed with reduced casting-to-stripping time, thus bearing out the results recorded graphically in Section I., Part D(1). It is important to note that the reduced casting-to-stripping times quoted in the Seventh Ingot Report (pp. 151 and 152) were obtained from average values; if the moulds had been subjected consistently *throughout their life* to a reduced stripping time this effect would probably have been much greater. If one stripping time in a series of short stripping times is specially long, any gain in life expected from the shorter average stripping time will be largely offset.

(b) *The Effect of Steel Composition.*—The average life of a batch of moulds used solely for a 0·25% carbon steel was compared with that of similar moulds into which a small proportion of steels with 0·40% of carbon and over were cast. The moulds used for the 0·25% carbon steels showed a 13% longer life. This result was in line with a previous experiment.

(c) *The Effect of High Casting Temperature of the Steel.*—Two instances are recorded. In the first case all the eighteen moulds used had to be scrapped and in the latter case seven out of the twenty-five used were no longer fit for service owing to scabby surface.

(d) *The Effect of Mould Temperature immediately before Teeming.*—The disastrous effect of teeming into hot moulds is well known and naturally no experiment was conducted intentionally to prove this, but by an examination of records it was shown that relatively small variations in the temperature of the mould (even only slightly above shop temperature) had a marked effect on mould life. The greater cooling effect in winter gave improved life compared with that in summer; also the longer the time interval between successive casts the higher was the life.

(e) *Other Deleterious Factors minimised by Improved Casting-Pit Technique.*—There was a marked improvement in mould life following the installation of cooling gantries.

Wider spacing of moulds as set for casting improved the life by permitting greater air circulation.

The opposite sides of moulds which are always set in contact with adjacent moulds tend to fail first by crazing of the working face, and improved life can be obtained by turning moulds through 90° for each casting.

In certain cases mould life has been improved by a gradual thickening of the mould wall in that region of the mould most prone to failure.

PART F.—*Modes of Failure of Ingot Moulds.*

Section I. would not be complete without reference to the modes of failure (crazing and premature cracking) of ingot moulds.

(1) *Disintegration of the Working Face (Crazing).*

In the initial stages of the work Mr. J. G. Pearce (a Member of the Sub-Committee) dealt fully with this aspect of the problem in a paper on "The Failure of Ingot Moulds for Steel Ingots. The Influence of Composition and Structure."[1] He explained in detail the mechanism by which crazing commenced and proceeded to ultimate failure. This, briefly, was due to oxidation and growth commencing in the graphite cavities and was accelerated when the working face reached the pearlite change point at a temperature of about 780° C., when a definite contraction took place. Thus, contraction of the working face would take place simultaneously with expansion immediately behind, giving rise at first to the formation of minute fissures and developing later the well-known crazy appearance.

Mould irons for withstanding cracking should contain coarse graphite and be of relatively open grain; mould irons to withstand crazing should be harder and of a finer-graphite structure. The two requirements are antagonistic, with the result that mould iron at its best is only a compromise. Reference was also made to the graphitising as well as to the carbide-stabilising constituents of the mould iron, such as silicon, aluminium, nickel and copper on the

[1] Seventh Ingot Report, pp. 184–195.

one hand and chromium, molybdenum and manganese on the other. These are arranged in descending order of the appropriate effect.

(2) *Premature Cracking.*

Cracks, whether of the "abrupt" or "gradually developing" type, are obviously due to the uneven distribution of temperature causing stresses in excess of the strength of the material at some point and time during the heating cycle. Points of weakness, at which cracks develop, may be due to bad design (abrupt changes in section); to residual stresses, the accumulation of kish, porosity or minute cracks due to indifferent founding; or to heterogeneity.

Liability to cracking may be somewhat minimised by employing a relatively soft iron (high carbon, coarse graphite) which can accommodate itself more readily to stress than one of harder quality. For this reason a softer iron is used for moulds of large capacity where failure due to cracking must be avoided.

Such, then, can be said, briefly, to be the reasons for cracking expressed qualitatively, and investigatory work in this field on moulds which have failed in service by major cracking has been undertaken.

(a) *Examination of an* 80-*Ton Slab Mould.*—An exhaustive test was conducted by the B.C.I.R.A. in co-operation with the manufacturer and user on a large slab mould which, owing to a crack, became unusable after casting the third ingot.

The failure was attributed to a number of factors, as follows:

(i) An abrupt change in wall thickness at the bracing-bar support.

(ii) Heterogeneity in structure (the graphite in the region of the crack was of the "feathery" type, as distinct from the coarser, more uniform and randomly orientated graphite flakes in other parts of the mould).

(iii) The particularly low tensile and transverse strength values in the region of the crack.

(iv) The mould ratio occupied a position in the graph, Fig. 2 (*see* Section I., Part D (2)), which showed that it was extremely liable to fail prematurely by cracking and suggested inadequate wall thickness.

(b) *Examination of Three* 6½-*Ton Slab Moulds.*—These moulds were identical in design and made at the same foundry. Two used under floor-casting conditions gave normal lives, whilst the third employed under pit-casting conditions failed after 18 heats.

Early failure of the third mould was attributed to:

(i) The sharp and distinct variation in structure between the top and bottom.

(ii) The relatively low transverse strength at the bottom of the mould where the crack originated.

(iii) The deleterious effect of casting in a sunk pit.

PART G.—*Other Work.*

(1) *Work Carried out but not Published.*

(a) *A New Structure for Ingot Moulds.*—In the early stages of the work of the Sub-Committee the B.C.I.R.A. had just developed a process on a laboratory scale whereby a fine-graphite structure could be imparted to high-carbon irons of relatively thick section, resulting in an increase in transverse strength from 14 tons to 20 tons per sq. in. The process involved the treatment of a titanium-bearing iron melt with carbon dioxide.

The possible improvement of iron for ingot moulds by this process was too important to be disregarded, and large-scale trials were conducted at the foundry of a member firm in co-operation with the B.C.I.R.A. The results were disappointing, there being little or no improvement in mould life. Subsequent examination of the mould-wall structure revealed that the graphite in the iron had not attained the degree of fineness anticipated.

(b) *Correlation of the Properties of Metal with Performance in Use.*—A large-scale investigation was in progress at the works of a member firm at the outbreak of war, but this work had to be discontinued, since it threw too great a burden on the foundry and locked up a substantial amount of hematite. The work involved the casting of a large test-piece under controlled conditions with each mould made. The test-pieces were examined by the B.C.I.R.A. and the properties correlated with the life and behaviour of the moulds in service. Up to the suspension of this work the results were too few to show any definite relationship between the factors involved.

(2) *Work Contemplated.*

(a) *High-Steel-Scrap Cupola Iron for Moulds.*—It is hoped to carry out field tests using this iron as a substitute for hematite for ingot moulds as soon as it becomes available.

It may be necessary to make the addition of other irons during the process of melting in order to obtain the properties required for ingot moulds.

(b) *The Influence of Annealing.*—The first tests originally carried out in this field were inconclusive, but it is still held, in some cases of premature cracking, that residual stresses due to founding practice may be the cause. The Sub-Committee are anxious to prove this, but it has been difficult to obtain appropriate examples coupled with the availability of the annealing-furnace capacity required.

(3) *A Further Questionnaire.*

The Sub-Committee issued a questionnaire in 1935 to all users of moulds, and the information thus obtained and the results of statistical examination appear in the Seventh Ingot Report.

A further questionnaire has been prepared, which it is hoped to

issue to all manufacturers as well as to users of ingot moulds. Whilst the replies to the first questionnaire proved of great value, it was always felt that these were incomplete without a knowledge of the influence of the factors involved in the founding of ingot moulds. An exchange of information on the founding as well as on the usage of ingot moulds will not only allow more accurate deductions to be drawn, but will result in a general improvement in ingot-mould life.

(4) *Bibliography.*

A comprehensive bibliography of the subject, covering the period 1899 to January, 1937, was compiled by The Iron and Steel Institute and British Cast Iron Research Association Librarians.[1]

SECTION II.—The Basic Causes of Cracking.

Whilst the causes of cracking can be expressed qualitatively, there are still insufficient quantitative data available on which to design moulds on a scientific basis with the object of eliminating cracking.

Cracking depends on the magnitude of the stresses set up in the mould and on the mechanical properties of the mould metal at room and at elevated temperatures, and until data are available on these aspects of the problem, moulds will continue to be designed by empirical methods.

The Sub-Committee soon realised, therefore, that fundamental work in this field should proceed concurrently with the more practical aspect, and as a first step instituted the Stresses in Moulds Panel to direct this side of the work, which is described below.

Part A.—*The Determination of the Temperature Gradients in the Wall of a Slab Mould.*

Only a very imperfect picture of the temperature distribution in a mould can be obtained from the known physical constants, and, since other important factors play a part, the Sub-Committee decided as a first step to obtain these data experimentally.

The investigation was carried out by the Technical Department of the British Iron and Steel Federation (with the generous co-operation of the Appleby-Frodingham Steel Co., Ltd.) on a 10-ton slab mould. Time-temperature curves were obtained from no fewer than thirty-two positions in adjacent walls which included the corner. The technique employed and the results obtained are given in the Eighth Report on the Heterogeneity of Steel Ingots,[2] pp. 278–294. The results show *inter alia* that :

[1] Seventh Ingot Report, pp. 195–213.
[2] *Iron and Steel Institute*, 1939, *Special Report No.* 25.

(i) Quite apart from the end effect, a wide variation in temperature exists between different parts of the working face of the mould. This is accounted for under (iii) and (iv) as well as by the greater mass effect of mould material at the corners.

(ii) There is a tendency for the broad side of the mould to bend inwards, bringing pressure to bear on the broad side of the ingot, particularly in that region where crazing is at its worst.

(iii) There is less overall lateral contraction of the ingot and less lateral expansion of the mould between the two broad sides compared with the other two.

(iv) There is a considerable early withdrawal of the ingot from the mould at the corners and narrow sides and no indication of this in the middle of the broad side.

The results as a whole suggest that before the stresses in a mould wall can be accurately calculated for any mould the temperature distribution must be determined experimentally. Data were also required on the physical and mechanical properties of mould material at room and at elevated temperatures.

PART B.—*Papers Presented for Publication through the Stresses in Moulds Panel.*

(1) *The Thermal Relations between Ingot and Mould. By T. F. Russell (English Steel Corporation, Ltd., Sheffield).*

Mr. Russell (a Member of the Panel) had already done considerable mathematical work in this field and in 1940 was induced by the Panel to publish his earlier work together with that undertaken later on behalf of the Panel.[1]

His paper includes a quantitative examination of Saitô's formulæ for the distribution of heat between ingot and mould.

Examples are worked out for circular and square ingots of the same cross-sectional area cast into moulds of different thicknesses. Curves show the temperature at different points in the ingot and moulds, the temperature distribution across a diameter and the total quantities of heat in the ingot and the mould at different times.

Curves are also drawn to show the effect of the mould ratio on the temperature cycle occurring in the ingot near to the mould wall and on the time taken for the temperature at the centre of an ingot to fall by certain amounts representing solidification. The latter indicate that solidification is accelerated by increasing the mould thickness until the mould ratio is about 0·8–1·0, but that a further increase has an inappreciable effect. Four sets of experimental results on the measurement of mould temperature are examined, and they show that the greatest difference between theory and practice is found at positions in the mould near the working face,

[1] *Journal of The Iron and Steel Institute*, 1941, No. I., pp. 163 P–191 P.

due doubtless to the effect of the air-gap forming between the ingot and the mould.

(2) *Thermal Stresses in Ingot Moulds. By T. Land (Research Department, Messrs. William Jessop & Sons, Ltd., Sheffield).*

The Panel are indebted to Mr. D. A. Oliver (a Member) for directing one of his staff to work on this problem. Although Mr. Land does not claim finality to his work, it follows in logical sequence upon that of Mr. Russell. Mr. Land's paper[1] includes the calculation of the stresses in a long circular mould, on the assumption that the physical properties of the mould iron are independent of temperature and of stress. Under these conditions it is shown that stresses at the outer surface are roughly equal to the ultimate strength of the mould iron. In a very thin mould, however, the stresses exceed those in one of normal thickness by about 20%.

Next, the theory is developed to take account of the plastic deformation and varying physical constants of the mould iron, and in these circumstances the stresses are shown to be approximately half the ultimate strength of the mould material.

Other sections deal with moulds of non-circular section and with end effects.

A further section points out that the surface stresses can be calculated from the measurement of the temperature and expansion of the outer mould surface, and the exact relationships are set out together with suggestions for further experimental work before expansion of the present work can be attempted. These are set out in Part C (3) below.

The last section gives the detailed mathematical analysis of stresses in long circular moulds of perfectly elastic material.

PART C.—*Laboratory Work.*

(1) *Work Done on the Mechanical and Physical Properties of Mould Material.*

The Stresses in Moulds Panel at first considered that representative material would best be obtained from an actual mould, and on request the Appleby-Frodingham Company went to considerable pains to cut the 10-ton slab mould used for the experimental temperature determinations into sections.

Work on this material conducted by the B.C.I.R.A included :

(i) The determination of transverse, tensile and Young's modulus values at room temperature and at 600° C. on ten test-pieces representing approved positions in the mould wall.

(ii) Dilatational tests on two test-pieces between room temperature and 830° C.

The results (under (i)) showed considerable heterogeneity as well

[1] *Journal of The Iron and Steel Institute*, 1943, No. I., pp. 75 P–93 P (this volume).

as the deleterious effect of service conditions on the properties of the mould material, particularly in the region of the working face. There was, however, insufficient material to carry out the mechanical tests at more than two temperatures.

(iii) The determination of Poisson's ratio was carried out at the Brown-Firth Research Laboratories on two samples obtained from this mould at 0·5, 1·0, 1·54 and 2·0 tons per sq. in.

The results revealed wide dissimilarity.

(2) *Work Done on Model Moulds.*

(a) *Residual Stresses due to Founding.*—Work was commenced at the Brown-Firth Research Laboratories on the determination of residual stresses in model moulds due to founding, in the as-cast condition and after receiving a stress-relieving anneal. The method adopted was to measure the distortion after a series of successive cuts.

The work was interrupted by enemy action, but sufficient data were obtained to indicate that the stress distribution was irregular.

It is hoped to continue the work under more favourable conditions.

(b) *The Measurement of the Variation of Strain with Temperature in the Wall of a Model Mould into which an Ingot has been Cast.*—This work was commenced by the B.C.I.R.A. and preliminary results were obtained, but the whole equipment was destroyed by enemy action, and the work was discontinued.

(3) *Further Work Contemplated.*

(a) *Representative Material.*—To procure material which is fully representative of the general run of moulds as cast is one of the chief difficulties, but it is hoped this can be met by inviting a number of mould-makers to cast two test blocks under controlled conditions concurrently with the casting of an ingot mould or moulds from the same ladle. The subsequent history of the mould or moulds will be recorded for reference.

(b) *Stress-Strain Curves.*—It is hoped to obtain stress-strain curves at temperatures up to 800° C. on this material in the as-cast condition and after receiving a stress-relieving anneal.

It is suggested that the tests be conducted in tension up to 300° C., in tension and compression between 300° and 500° C. and in compression above 500° C. It is also desirable to know how the strain varies with the rate of loading in the plastic range.

(c) *Poisson's Ratio.*—This has yet to be determined accurately at the temperatures and stresses employed for the mechanical tests.

(d) *Large-Scale Experiment involving the Measurement of Strain and Temperature in the Wall of a Commercial Mould into which an Ingot has been Cast.*—This would be a more direct attack on the problem compared with the mathematical determination of stress, and, as suggested in Mr. Land's paper, should be useful in checking

and interpreting the calculated values. The two methods are complementary and together should make it possible not only to recommend sound practice in mould design but also to develop and test improved materials for ingot-mould manufacture.

Part D.—*A Technique for Determining the Temperature in the Interior of a Freezing Ingot.*

Following upon the presentation of Mr. Russell's paper it was believed that (in the large-scale experiment envisaged for the determination of heat distribution, concurrently with the measurement of strain, in the mould wall) it would be desirable to know accurately the temperature conditions within the freezing ingot. This was also of considerable interest to the Ingot Committee on metallurgical grounds. The method of inserting couples through the mould wall had often failed owing to the shearing action of the ingot during contraction. There was also a tendency for the sheath to bend upwards owing to buoyancy. The latter effect was observed also when sheaths were inserted into the molten steel from above.

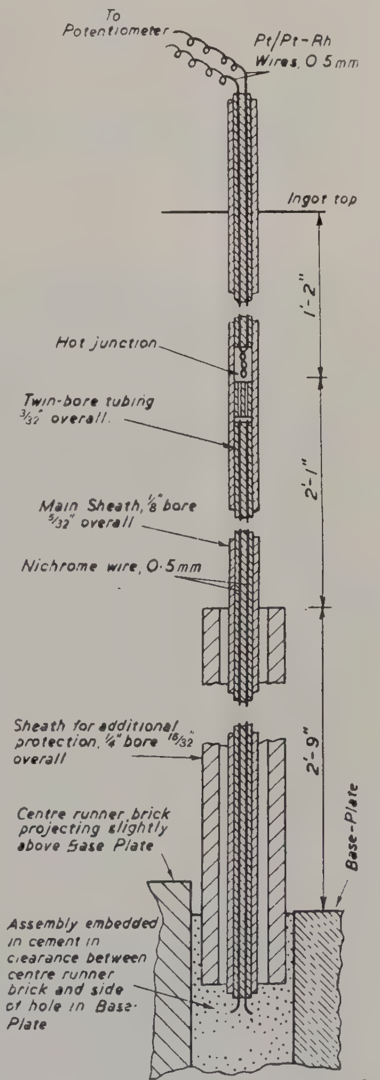

Fig. 9.—Assembly of Thermocouple for Ingot Temperature Measurement.

A technique was devised and a works experiment was conducted by the author of this review through the courtesy of the late Mr. R. P. Smith. Fig. 9 is a diagram of the assembly. The couple, encased in a slender silica sheath, was anchored to the base-plate and was thus supported in the ingot mould in a vertical position owing to buoyancy. The experiment (carried out merely to prove the technique) was

conducted on a 48-cwt. uphill-cast ingot using a silica sheath of only $\frac{5}{32}$-in. outside diameter. Thus the time-lag was reduced to a minimum. A time-temperature curve was obtained for that position in the freezing ingot where it is most difficult to maintain the silica sheath intact, *viz.*, in the last portion to freeze immediately below the head.

The result proved that by this means a large number of accurate temperature determinations could be made concurrently at different positions in the freezing ingot, at least for ingots cast uphill.

Summary and Conclusion.

The results of the foregoing researches taken as a whole indicate a number of ways by which the performance of ingot moulds may be improved. These include reduced casting-to-stripping time, adequate cooling facilities, correct wall thickness, correct composition of mould material, improved founding technique in manufacture, and improved casting-pit practice as a whole.

They point to the disregard which designers of steel plant have had in the past for providing adequate accommodation and equipment whereby moulds might receive the treatment consistent with the important position that they occupy on the cost sheet.

They suggest that fundamental research should proceed concurrently with work on the more practical side, if for no other reason than to obtain accurate data for designing moulds which will not crack, as against the empirical methods at present used. Some results of such fundamental work are given in Section II.

Up to the present, however, much more valuable results have been obtained from works experiments and the study of works records than from fundamental laboratory work.

It seems, therefore, that, despite war conditions, every effort should be made to ensure that each works should keep full and accurate records of mould history, not only for control within the works but also for collective research purposes.

THERMAL STRESSES IN INGOT MOULDS.*

BY T. LAND, M.A. (RESEARCH DEPARTMENT, MESSRS. WILLIAM JESSOP AND SONS, LTD., SHEFFIELD).

Paper No. 20/1943 *of the Committee on the Heterogeneity of Steel Ingots (submitted by the Stresses in Moulds Panel of the Ingot Moulds Sub-Committee, a Joint Sub-Committee of the Heterogeneity and Open-Hearth Committees).*

SUMMARY.

Cracking, caused by the thermal stresses set up during the casting of ingots, is a frequent cause of ingot-mould failure. A more exact knowledge of the effect of ingot-mould shape and the properties of the ingot-mould iron on the magnitude of the thermal stresses would be of immediate practical value. With this consideration in mind the thermal stresses under certain conditions have been calculated. The paper has been divided into two parts. In Section 1 of Part I. the stresses in a long circular mould have been calculated on the assumption that the physical properties of the ingot-mould iron are independent of temperature and of stress. It is shown that under these conditions the stresses at the outer surface would be roughly equal to the ultimate strength of the ingot-mould iron. The stresses in a very thin mould exceed those in one of normal thickness by about 20%. In Section 2 the theory is developed to take account of the plastic deformation and varying physical constants of the cast iron, and in these circumstances the stresses are shown to be approximately half the ultimate strength of the mould material. Section 3 deals with moulds of non-circular section and Section 4 with end effects. In Section 5 it is pointed out that the surface stresses can be calculated from measurement of the temperature and expansion of the outer mould surface, and the exact relationships are set out. Arising out of this investigation suggestions are made for future experimental work. Part II. of the paper gives the detailed mathematical analysis discussed under Section 1 of Part I.

INTRODUCTION.

SEVERAL years ago Members of the Ingot Moulds Sub-Committee under the Chairmanship of Mr. R. H. Myers were fully aware of the desirability of pursuing both theoretical and experimental investigations into the performance and cause of failure of ingot moulds. The early investigations of the Sub-Committee were almost exclusively concerned with accumulating and analysing service data in steelworks, in order to throw light upon the extremely variable ingot-mould lives which have been characteristic of many steelworks in this country and abroad. Valuable experimental data were accumulated and set out in the First and Second Reports

* Received September 25, 1942. This paper is published by authority of the Committee on the Heterogeneity of Steel Ingots. The views expressed in it are the author's, and are not necessarily endorsed by the Committee as a body.

of the Ingot Moulds Sub-Committee.[1, 2] In 1939 a small Panel of the Ingot Moulds Sub-Committee was formed under the Chairmanship of Mr. G. Stanfield to study both theoretically and experimentally the stresses which were set up in ingot moulds during the teeming of liquid steel. The present research was carried out for the Stresses in Moulds Panel and is now put forward as a contribution towards the elucidation of some of the problems which are its special concern.

Part I.—*The General Problem and its Solution.*

One important type of ingot-mould failure is cracking due to the thermal stresses set up during the casting of ingots. Although the cause of the cracks is well known, there is at present little detailed information to assist the designer to produce moulds which will resist cracking. It is likewise not very clearly understood what mechanical properties should be sought in choosing the ingot-mould material. A method of calculating or measuring the stresses set up in moulds of different shapes and materials is clearly necessary.

The mathematical problem is one which defies an exact solution. The moulds normally used are of varied and complicated shapes and the physical properties of the ingot-mould material vary widely with temperature. In spite of the complexity of the subject it is, however, possible to derive approximate solutions to some of the simpler problems. In addition certain general relationships can be given which allow us to delineate, in its broadest outline, the picture of the stresses set up in moulds of complicated shapes. A body of information is presented which should prove useful when more experimental work is attempted.

The problem is approached in five stages. In the first section the case of a long cylindrical ingot mould is discussed on the assumption that the mould material remains perfectly elastic and that its elastic constants do not vary with temperature. Section 2 is an attempt to gauge the effect of the plastic deformation of the mould. In Section 3 the case of a long non-circular mould is considered and Section 4 deals with end effects.

The stresses at the outer surface of the mould are almost certain to be the criterion of the tendency of the mould to crack. These stresses can be deduced from strain and temperature measurements made on the surface of the mould. The exact relationships are given in Section 5, so that, when careful measurements of surface strain are made, the strains can be interpreted in terms of stresses and hence used to examine the validity of the various expressions derived in the earlier sections of the paper.

(1) *Long Cylindrical Moulds of Uniformly Elastic Material.*

In this section the case is treated of open-ended moulds of circular cross-section long enough to make the effect of the ends negligible

at the point considered. This shape is amenable to formal treatment and the information derived from its study will be found useful when more complicated shapes are considered. The material is assumed to be perfectly elastic and the elastic constants to be independent of temperature. It is clearly recognised that these conditions are far from representing those actually attained in practice. It does, however, provide a basis for the investigations to which refinements can be added later. It should be noted that while the elastic constants vary widely with temperature the value of $E\alpha/(1 - \nu)$,* which is the form in which they are combined in the stress formulæ, is much more nearly constant.

Without going into detail it is possible to see the general effect on the mould of casting an ingot in it. When the metal is poured into the mould the inner layer of the mould is heated to a bright red-heat. At this temperature the inner ring of the mould material tries to expand. The expansion is resisted by the outer layers of the mould which are still cold. This conflict results in a compressive hoop stress in the inner part of the mould and a tensile hoop stress in the outer part. At the same time the material of the mould suffers a radial compression. The hot inner part of the mould also tries to expand in the axial direction. The cool outer portion of the mould resists this tendency, and thus there is an axial compressive stress inside the mould and an axial tensile stress in the outer part.

The details of the mathematical analysis of the problem will not be of interest to the general reader and they have therefore been discussed separately in the second part of the paper. The analysis follows the classical theory of stresses in hollow cylinders, the equations for the temperature distribution being based chiefly on the work of Saitô,(3) which was tested experimentally by Russell.(4)

Two of the moulds which Russell dealt with in his paper have been chosen and the stresses at the inner and outer surfaces have been calculated on the assumptions outlined above. In each case the ingot is $93\frac{1}{3}$ cm. in dia. and the moulds chosen are 20 and $6\frac{2}{3}$ cm. thick respectively. The corresponding mould ratios † are 1·014 and 0·306.

The following values have been assigned to the physical constants of the ingot mould.

Young's modulus	$= 2{\cdot}67 \times 10^3$ tons per sq. in.
Coefficient of linear thermal expansion	$= 13{\cdot}3 \times 10^{-6}$ per ° C.
Poisson's ratio	$= 0{\cdot}25$
Newton's law cooling constant (h)	$= 0{\cdot}015$ c.g.s. units.
Thermal diffusivity (a^2)	$= 0{\cdot}10$ c.g.s. units.

The effective temperature of the metal cast is taken as 1600° C. above the initial temperature of the mould and the surrounding air,

* For notation, *see* Part II.

† The mould ratio is the ratio of the cross-sectional areas of the mould and ingot.

which are taken as zero. This value is chosen to keep the temperature calculations in line with those of Russell. Any different values of this temperature or of the first three of the constants may be allowed for by multiplying the stress by a factor which is the same for all stresses at all times.

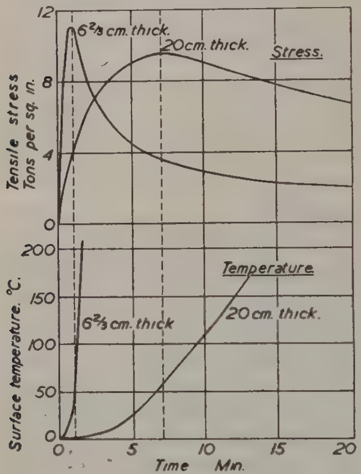

FIG. 1.—The Temperatures and Thermal Stresses at the Outer Surfaces of Two Circular Ingot Moulds, calculated on the assumption that the thermal and elastic constants are independent of temperature and of stress.

The results of the calculations are presented in graphical form showing how the surface stresses rise to a maximum value and then fall away again. The tensile stresses at the outer surface of the two moulds are shown in Fig. 1. The temperatures at the outer surfaces are shown on the same diagram. The two stress curves are of very similar form but the time scales are approximately in the ratio of the squares of the thickness of the moulds. In each case the stress reaches its maximum value when the surface temperature has risen by about 60° C. It will be noticed that the surface of the thin mould reaches a maximum stress some 18% greater than the thick mould.

The stresses at the inner surface are of less practical importance but they have been calculated and are shown in Fig. 2. It will be observed that the maximum compressive stress is the same in each case, but the thin mould remains under a high stress for a much shorter time. This may be one reason why thick moulds show a greater tendency to craze than thin moulds. The value of the calculated maximum tensile stress at the outer surface is about the same as the true breaking stress at room temperature for a cast iron of this type, but the initial compressive stress at the inner

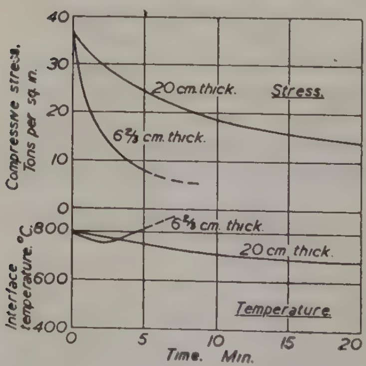

FIG. 2.—The Temperatures and Thermal Stresses at the Inner Surfaces of Two Circular Ingot Moulds, calculated on the assumption that the thermal and elastic constants are independent of temperature and of stress.

surface is far in excess of any which could be maintained at high temperatures. It is clear that considerable plastic deformation will occur in the inner layers of the mould.

(2) *The Effect of Plastic Deformation.*

When the stress-strain curve becomes non-linear the problem passes beyond the range of the classical mathematical theory. It is possible, however, to use an approximate graphical method * for computing the thermal stresses from the true stress-strain curves of samples of mould material measured at different temperatures. To do so certain assumptions must be made.

In Part II. of the paper the equations relating the stresses and strains under elastic conditions are fully set out. Two of these are important at this stage and will be discussed in detail. Equation (9) gives the axial stress (σ_z) at any point in the mould wall and may be written:

$$\sigma_z = \frac{E\alpha}{1 - \nu}\{f(t) - \theta\}$$

This is the same as the equation for the stress in an infinite plane slab which is not allowed to distort, but is allowed to expand by an amount $\alpha f(t)$ in the directions of its length and breadth.

The physical meaning of the equation when applied to the slab is quite simple. The total linear expansion of the material is $\alpha f(t)$, but of this an amount $\alpha\theta$ is due to the thermal expansion. The remainder, namely, $\alpha\{f(t) - \theta\}$, is due to the stress σ_z. If this stress were applied only in one direction, we should write:

$$\sigma_z = E\alpha\{f(t) - \theta\}$$

Since the stress is applied in the direction both of the length and of the breadth the factor $1/(1 - \nu)$ is introduced.

Let us consider how it comes about that the same equation is applicable to the long cylindrical mould. Equation (6) in Part II. gives the relationship between the radial, tangential and axial stresses under elastic conditions:

$$\sigma_z = \sigma_r + \sigma_\phi$$

Thus the axial stress is equal to the sum of the two stresses acting at right angles to the axis. Putting $\varepsilon_r = \sigma_r/E$, &c., we may now write $\varepsilon_z = \varepsilon_r + \varepsilon_\phi$. The strain in the axial direction resulting from the two stresses σ_r and σ_ϕ will be $\nu(\varepsilon_r + \varepsilon_\phi)$, which is the same as the strain $\nu\varepsilon_z$ that would be produced by a single stress equal to σ_z in, say, the tangential direction. This accounts for the identity of the expressions for the stresses in slab and cylinder.

In developing a theory which will take account of the non-linear stress-strain relationship with which we have to deal for cast

* A similar method, applied to a simpler problem, has been described by White.[5]

iron, it will be assumed that we may still calculate the axial stress in a cylindrical mould by analogy with an infinite slab. This is an approximation, for the relationship $\varepsilon_z = \varepsilon_r + \varepsilon_\phi$ no longer holds exactly. However, the maximum value of radial stress in moulds of normal thickness never becomes more than about 15% of the maximum axial stress, and it is therefore unlikely that the error will be serious.

Making this approximation we can now proceed to calculate the axial stresses. We need a further condition to obtain our solution, namely, that the total force acting on any cross-section of the mould perpendicular to the axis is zero. This is, of course, equally true for plastic and elastic conditions.

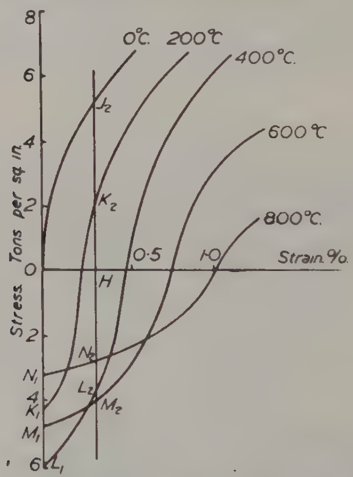

FIG. 3.—The (Fictitious) Stress-Strain Curves for Ingot-Mould Iron. The strain axis has been contracted in the ratio $(1 - \nu)$ so that the curves become applicable to the case of equal stresses acting in two perpendicular directions.

The only experimental data usually available are the stress-strain curves taken when the stress is applied in one direction only. In the ingot mould—or rather in the equivalent slab which we shall be considering—equal stresses are applied in two perpendicular directions. Under these conditions the linear strain corresponding to a given stress is reduced in the ratio $(1 - \nu)$. In Fig. 3 the curves represent true stress-strain curves taken on normal test-pieces, but the strain axis has been contracted in the ratio $(1 - \nu)$ so that the curves become applicable to the case of equal stresses acting in two perpendicular directions. Poisson's ratio (ν) is usually applied only to elastic deformation, but the use of the symbol in the following analysis is extended to cover plastic deforma-

tion. Different values for ν have been taken at different temperatures, and there is no reason why different values should not be taken at different stresses if that should be necessary. The origin of each curve has been moved to the right by an amount $\alpha\theta$, where θ is the temperature of the test. The intercepts on the stress axis (OK_1, OL_1 ....) represent the stresses necessary to restrain completely the thermal expansion of a thin plate of the mould material in the directions of its length and breadth when heated to different temperatures.

If we assume a certain temperature distribution in the mould wall, Fig. 4, we can immediately deduce the stress distribution which would be set up if the length of the mould were forced to remain constant. This is done by plotting the intercepts OK_1,

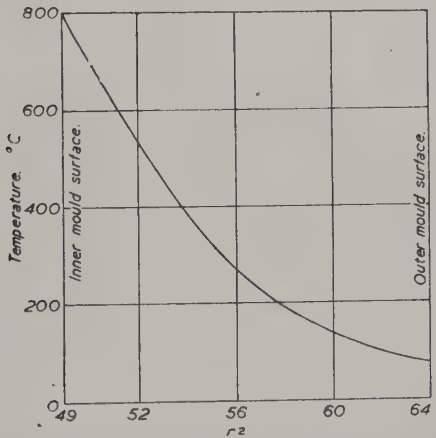

Fig. 4.—The Temperature Distribution in the Wall of a Circular Ingot Mould, 93⅓ cm. in dia. and 6⅔ cm. thick, 1 min. after casting.

OL_1, &c., in Fig. 3 corresponding to each temperature, Fig. 5. If, instead of plotting the distance r of each point from the centre of the mould as our abcissa, we plot the area s of the circle of radius r, then the area OP_1Q_1R (Fig. 5) represents the total force on a cross-section of the mould. Suppose that we now allow the mould to expand uniformly in the axial direction, the stress will be relieved and the area OP_1Q_1R (taking account of sign) will decrease and eventually vanish. The curve PQ at various stages can be plotted as follows: An expansion of the mould by an amount e corresponds to a point H on the strain axis, Fig. 3, at a distance e from the origin. The stresses required to restrain the thermal expansion to an amount e are given by the intercepts HJ_2, HK_2, &c., on a line through H parallel to the stress axis. These new stresses can be

plotted directly on the stress diagram of Fig. 5. The equilibrium conditions can readily be found by successive approximations, using a planimeter to measure the area between the curve PQ and the axis OR. With a little experience the correct curve can be obtained sufficiently accurately at the second or third approximation.

The true stress-strain curves of ingot-mould iron at different temperatures will vary considerably with the type of iron used. The curves shown in Fig. 3 are thought to be fairly representative of the type of iron normally used in the manufacture of ingot moulds. The curves of Fig. 4 and Fig. 5 have been drawn using the dimensions

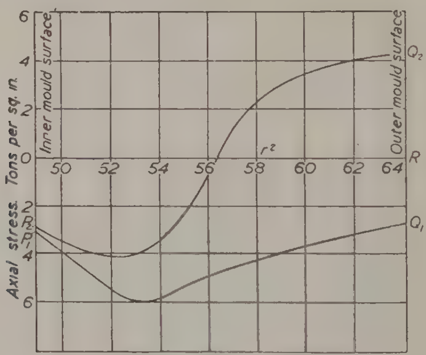

FIG. 5.—Stress Diagram for the Temperature Distribution shown in Fig. 4.

and the calculated temperature distribution of the thin mould treated in Section 1, one minute after casting.

The following values have been assigned to Poisson's ratio and the mean coefficient of linear thermal expansion at different temperatures:

	0° C.	200° C.	400° C.	600° C.	800° C.
α .	...	$11{\cdot}1 \times 10^{-6}$	$12{\cdot}0 \times 10^{-6}$	$12{\cdot}5 \times 10^{-6}$	$12{\cdot}5 \times 10^{-6}$
ν .	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$

The stresses at other times have been calculated by the same graphical method and the development of the axial stress at the outer surface is presented in Fig. 6. On the same diagram the stresses calculated on the elastic theory of Section 1 have been plotted. The value of Young's modulus in this case has been chosen as 1060 tons per sq. in., so that the maximum stresses on the two curves are identical. It is interesting to see that the curves are of similar shape and that the maximum stresses occur at the same time. The value of the maximum stress attained is quite reasonable, being about half the breaking stress for this type of iron. A reason-

ably accurate estimate of the radial stresses may be made using the formula :

$$\sigma_r = \frac{1}{r^2}\int_b^r r\sigma_z dr,$$

which is applicable to the elastic condition and is probably not greatly in error for the plastic condition. The maximum radial stresses in the moulds considered would be about 0·2 ton per sq. in. for the mould with a mould ratio of 0·30, and about 0·7 ton per sq. in. for one with a ratio of 1·47. Before we could draw conclusions about the numerical values it would be necessary to make careful determinations of the mechanical properties of ingot-mould iron at various temperatures. In particular the true stress-strain curves

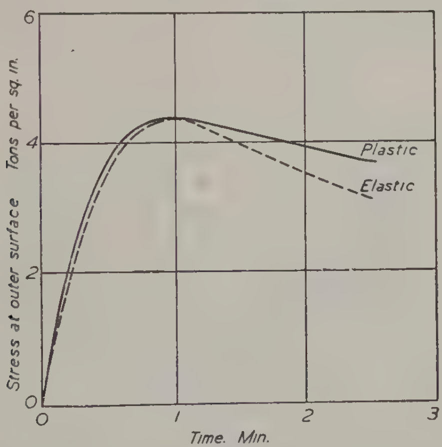

FIG. 6.—The Thermal Stresses at the Outer Surface of the Ingot Mould $6\frac{2}{3}$ cm. thick, as calculated on the elastic and plastic theories. For the "elastic" curve Young's modulus has been assigned a value giving the same maximum stress as that calculated on the plastic theory.

in tension and compression at temperatures up to 800° C. would be essential.

The effect of the thickness of the mould wall is sufficiently important to be considered in some detail. It is known from experience that thin moulds are more liable to cracking than thick moulds [(2)] and the theory explains why this is so. In Section 1 it was shown that the maximum tensile stress in the thin mould under elastic conditions would be nearly 20% greater than in the thick mould. The difference is partly caused by the different temperature distribution in the mould and partly by the very shape of the mould. Under imperfectly elastic conditions the difference appears to be less marked. Using Russell's curves for the temperature distribu-

tions in moulds of different thicknesses, the stresses at the mould surfaces have been calculated by the graphical method described above. The maximum tensile stress is only reduced from 4·3 tons per sq. in. to 3·9 tons per sq. in., even when the mould ratio is increased from 0·30 to 1·46. This difference, however, is likely to be accentuated by the creep which will occur in the hot parts of the mould and which will continue for a longer period before the maximum stress is reached in the thick mould. This emphasises the point that high-temperature tests on the ingot-mould iron should be taken at different times after the application of the load if accurate calculations are to be made.

(3) *Long Non-Circular Moulds.*

Moulds of the complex shapes usually found in steelworks are very difficult to treat mathematically. There is at present no simple

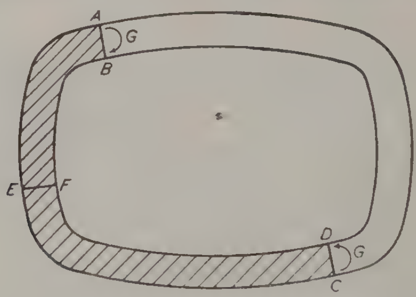

Fig. 7.—Section of a Symmetrical Ingot Mould.

means of calculating the exact temperature distribution in such moulds. Even if such means were available the stress distribution would be difficult to deduce. It is possible, however, to derive a fair amount of information about non-circular moulds by extension of the theory of circular moulds. The method involves very little mathematical work and depends on a few simple principles of statics. Although the problem is not solved quantitatively, qualitative answers can be given to many of the questions which arise.

The large majority of ingot moulds are of symmetrical section. Fig. 7 shows a section of a mould which is taken at a point sufficiently far from the ends for it to be considered as part of an infinitely long mould the ends of which are under no constraint. Let us investigate the forces acting on a section of the mould bounded by two parallel planes perpendicular to the axis of the mould, and two other parallel planes *AB* and *CD* perpendicular to the wall surface and parallel to the axis. *AB* and *CD* are in equivalent positions and split the mould into two identical halves.

Since we are dealing with an infinitely long mould, when we

consider the equilibrium of the section $ABCD$ we may neglect the forces acting on the two surfaces perpendicular to the axis, as these will be equal and opposite. The forces acting on either of the surfaces AB and CD may be resolved into three perpendicular forces and three perpendicular couples. From a consideration of the symmetry of the figure it can readily be shown that for equilibrium all these forces and couples must vanish except the couple in the direction of the axis of the mould. This couple we will call G. A consideration of the equilibrium of any other section of the mould such as $ABEF$ will show that the couple acting on the surface EF is equal to G.

Now, this is a very important conclusion, as it determines the deformation and the consequent stress distribution of a long non-circular mould. In a circular mould the value of the couple G is determined entirely by the temperature distribution. At any point in a non-circular mould the wall will have a certain curvature. In a circular mould of that curvature with the same temperature distribution there would be a couple, which we will call G_t, acting on a vertical section through the mould wall. If the non-circular mould were constrained to remain in its original shape without distortion this is the couple which would act on a vertical plane section at this point. The couple would, of course, be different for each part of the mould. We have shown, however, that in the absence of constraint this is not a permissible state of equilibrium. The mould, therefore, distorts, causing an additional couple G_b due to the bending of the mould wall at that point, and the distortion will be such that $G_t + G_b$ is the same for all plane sections of the mould parallel to the axis. This does not mean that the stress distribution will be identically the same on every vertical section, but the different stress distributions will produce the same couple in each case. Now, it is fairly clear that the two couples G_t and G_b will have quite similar stress distributions, and we should not expect the hoop stress at the outer surface to vary by more than perhaps $\pm$ 20% as we traverse the periphery of the mould. This is a very useful conclusion, as it means that the hoop stresses in a non-circular mould should not differ greatly from those in a circular mould of similar mould ratio, and that only relatively small variations from this mean value should occur at the corners and faces. The calculations of the exact stress distribution at different parts of the mould will not be attempted, as it is not thought that the results would be very reliable. Such an enquiry is better conducted experimentally.

The foregoing remarks apply, of course, only to the hoop stresses. There is no reason for the axial stresses to be equalised round the mould and we may expect them to be highest where the temperature differences are greatest, that is, in the middle of the mould faces. The axial stresses, indeed, will not differ greatly from those calculated on the plastic theory developed in Section 2. The temperature distribution may be measured and the stresses computed graphically

as has been explained. A certain error will arise owing to the difference between axial and hoop stresses at the corners and face centres, but this should not be more than, say, 15%.

(4) *End Effects.*

The closed end of a mould is not likely to produce very large variations of stress, but near an open end there will be a reduction of the axial stresses and an increase in the tensile hoop stresses. The case of a thin circular cylinder has been studied (6) and the effect of the temperature variation along the axis of the cylinder has also been investigated for a steady thermal state. (7) Mathematical expressions can be derived for the condition of an open-ended circular ingot mould, but the expressions obtained are of such complexity that the arithmetical work involved in interpreting them is quite prohibitive. It is sufficient to say that the maximum tensile hoop stress at the free end of the mould is increased by about 25%. The effect of the free end extends down the mould to a distance of approximately $0{\cdot}4\sqrt{B^2 - b^2}$. The effect of the variation of temperature along the length of the mould is to spread this increased stress over a greater distance from the open end. For non-circular moulds the effects are more complicated. In a slab mould, for example, we should expect relatively little distortion at the corners and a tendency for the mould to trumpet out at the ends of the flat faces, but this is another case in which speculation is much less fruitful than experiment.

(5) *The Calculation of Stresses from Measurements of Surface Strain and Temperature.*

An investigation of the theoretical stresses in ingot moulds would hardly be complete without some indication of how the results can be checked experimentally. This is fortunately not difficult even when the stresses pass beyond the limits of proportionality. At the surface layer of the mould the relation of the stresses and strains is reduced to a two-dimensional problem. Taking two perpendicular axes X and Y lying on the mould surface we can write :

$$e_x = \bar{a}\theta + \frac{\sigma_x}{E_x} - \nu\frac{\sigma_y}{E_y}$$

$$e_y = \bar{a}\theta + \frac{\sigma_y}{E_y} - \nu\frac{\sigma_x}{E_x}$$

$$\gamma_{xy} = \frac{1}{G} \cdot \tau_{xy}$$

where E_x is the ratio of stress to strain at stress σ_x and $\bar{\alpha}$ is the mean coefficient of thermal expansion over the range of temperature 0 to θ. From these equations we find that :

$$\frac{\sigma_x}{E_x} = \frac{e_x + \nu e_y}{1 - \nu^2} - \frac{\bar{a}\theta}{1 - \nu}$$

$$\frac{\sigma_y}{E_y} = \frac{e_y + \nu e_x}{1 - \nu^2} - \frac{\bar{a}\theta}{1 - \nu}.$$

From an experimental tensile test the value of σ corresponding to a given strain σ/E can be found. Thus the measurement of the expansion of the mould surface in two perpendicular directions, together with the surface temperature, gives sufficient data to determine the stresses at the outer surface. The shearing stress can, of course, be obtained directly from the shearing strain. The expansion of the mould could be measured conveniently with extensometers of the Huggenberger type. Since the greatest stresses are at the surface of the mould there seems to be very little point in measuring the stresses at other points. The full stress distribution could, if desired, be calculated from measurements of the temperature and of the axial and radial expansions at points within the mould wall. These might be measured by boring holes to a certain depth in the mould surface, but the presence of the holes would disturb the stress distribution to some degree, and it is in any case doubtful whether the information derived would be of any practical value.

In these calculations the residual stresses in the mould have been neglected. As the mould cools slowly from a dull red-heat after each casting the residual stresses are probably not very large. It would, however, be very interesting if it were possible to follow the expansion and contraction of a carefully annealed mould through a number of casting cycles. It is just possible that in certain designs of ingot moulds the residual stresses might build up cumulatively to dangerous proportions.

(6) *Conclusions.*

The purpose of the present paper is to prepare the way for experimental work. The theoretical development clearly suggests two distinct lines of approach. In the first place the calculation of thermal stresses from measured or computed temperature distributions demands a more detailed knowledge of certain physical properties of the ingot-mould iron than has so far been available. It will perhaps be useful to set out these properties, so that the scope of the necessary work can be seen at a glance. We require to know the following:

(1) The true stress-strain curves of the cast iron at temperatures up to 800° C. The tests should be in tension for temperatures up to 300° C., in both tension and compression between 300° and 500° C. and in compression from 500° to 800° C. Under plastic deformation at high temperatures it is important to know how the strength varies with the rate of loading.

(2) Poisson's ratio at the stresses and temperatures laid down for the mechanical tests.

(3) The coefficient of thermal expansion at temperatures up to 800° C.

When these properties are known it will not be difficult to calculate the thermal stresses in circular moulds and to estimate the stresses in moulds of other shapes.

The second approach to the problem is to measure the temperature and the expansion, in two perpendicular directions, of the mould surface. This is a much more direct attack on the problem and should be most useful in checking and interpreting the calculated values. The two methods are complementary and together should make it possible not only to recommend sound practice in mould design, but also to develop and test improved materials for ingot-mould construction.

Part II.—*The Mathematical Theory of the Stresses in Long Circular Moulds of Perfectly Elastic Material.*

The general problem of thermal stresses in concentrically heated cylinders was solved many years ago by Duhamel.(8) The theory has been applied to cylinders in a steady thermal state in the study of the design of Diesel engines.(9) In the same connection the effect of cyclic variations of temperature has been studied,(10) and other applications have been discussed by Lees (11) and by Gatewood.(12) So far as the author is aware the theory has not previously been applied to the conditions encountered when steel is cast in a cast-iron ingot mould.

The following notation has been adopted:

σ_r, σ_ϕ and σ_z are the radial, tangential and longitudinal fibre stresses (tensions) at a point the cylindrical co-ordinates of which were originally (r, ϕ, z).
e_r, e_ϕ and e_z are unit elongations in the r, ϕ and z directions.
θ is the temperature at the point (r, ϕ, z) at time t.
θ_I is the temperature of the mould-metal interface.
θ_0 is the casting temperature of the molten metal.
B is the external radius of the mould.
b is the internal radius of the mould.
L is the thickness of the mould.

The following are the thermal and elastic constants of the mould material:

c is the specific heat.
κ is the thermal conductivity.
ρ is the density.
a^2 is the thermal diffusivity.
α is the coefficient of linear thermal expansion.
E is Young's modulus.
ν is Poisson's ratio.
g is the Newton's law emissivity constant of the mould surface.

$h = \frac{g}{\kappa}$.

μ_n is the nth root of the equation:

$$H = hB = \frac{\mu J_1(\mu)}{J_0(\mu)}.$$

$$A_n' = \frac{2b}{B} \cdot \frac{\mu_n J_1\left(\frac{\mu_n b}{B}\right)}{(H^2 + \mu_n^2)J_0^2(\mu_n)}.$$

J_0 is the Bessel function of the first kind (order zero).
J_1 is the Bessel function of the first kind (first order).

The temperature of the surroundings and the initial temperature of the mould are taken to be zero.

Consider a hollow cylinder of perfectly elastic isotropic material the elastic constants of which do not vary with temperature. The boundary conditions assumed are as follows :

(1) There is no normal stress on either surface, *i.e.*, $\sigma_r = 0$, at $r = b$ and at $r = B$.
(2) There is no shear force acting on either surface.
(3) The ends are free from constraint, but sufficiently distant not to affect the stress distribution. In these circumstances any plane cross-section will remain plane and $\partial e_z/\partial r = 0$.
(4) There are no body forces and hence $\int_b^B r\sigma_z dr = 0$.

Under these conditions it is not difficult to show that the radial, axial and tangential directions form the principal axes of stress.

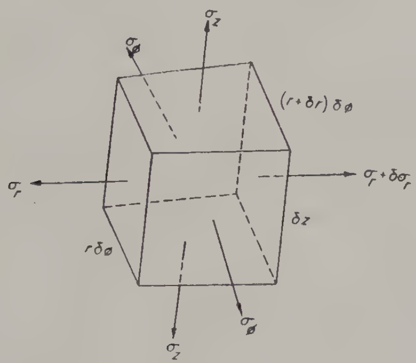

FIG. 8.—Forces operating on an Element.

The shear forces on the element illustrated in Fig. 8 will then be zero and we may write :

$$e_r = \alpha\theta + \frac{1}{E}(\sigma_r - \nu\sigma_\phi - \nu\sigma_z) \quad \ldots\ldots \quad (1)$$

$$e_\phi = \alpha\theta + \frac{1}{E}(\sigma_\phi - \nu\sigma_x - \nu\sigma_z) \quad \ldots\ldots \quad (2)$$

$$e_z = \alpha\theta + \frac{1}{E}(\sigma_z - \nu\sigma_r - \nu\sigma_\phi) \quad \ldots\ldots \quad (3)$$

From the geometry of the system it will be seen that :

$$e_r = e_\phi + r\frac{\partial e_\phi}{\partial r} \quad \ldots\ldots \quad (4)$$

Resolving the forces acting on the element in the radial direction we have :

$$\sigma_\phi = \sigma_r + r\frac{\partial \sigma_r}{\partial r} \quad \ldots\ldots \quad (5)$$

With the boundary condition stated above we find that these equations lead to the further relation:

$$\sigma_z = \sigma_r + \sigma_\phi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Using equations (4), (5) and (6), the first three equations can be solved for the stresses, and on integration we find that: [6]

$$\sigma_r = \frac{Ea}{1-\nu}\cdot\frac{1}{r^2}\left\{\frac{r^2-b^2}{B^2-b^2}\cdot\int_b^B r\theta dr - \int_b^r r\theta dr\right\} \quad . \quad . \quad . \quad (7)$$

$$\sigma_\phi = \frac{Ea}{1-\nu}\cdot\frac{1}{r^2}\left\{\frac{r^2+b^2}{B^2-b^2}\int_b^B r\theta dr + \int_b^r r\theta dr - r^2\theta\right\} \quad . \quad (8)$$

$$\sigma_z = \frac{Ea}{1-\nu}\cdot\left\{\frac{2}{B^2-b^2}\int_b^B r\theta dr - \theta\right\} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Writing $Q(r) = \int_b^r r\theta dr$ these equations become:

$$\sigma_r = \frac{Ea}{1-\nu}\cdot\frac{1}{r^2}\left\{\frac{r^2-b^2}{B^2-b^2}\cdot Q(B) - Q(r)\right\} \quad . \quad . \quad . \quad . \quad (10)$$

$$\sigma_\phi = \frac{Ea}{1-\nu}\cdot\frac{1}{r^2}\left\{\frac{r^2+b^2}{B^2-b^2}\cdot Q(B) + Q(r) - r^2\theta\right\} \quad . \quad . \quad (11)$$

$$\sigma_z = \frac{Ea}{1-\nu}\cdot\left\{\frac{2}{B^2-b^2}\cdot Q(B) - \theta\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

The shear stresses are:

$$\tfrac{1}{2}(\sigma_\phi - \sigma_z),\ \tfrac{1}{2}(\sigma_z - \sigma_r),\ \tfrac{1}{2}(\sigma_r - \sigma_\phi).$$

From (6) these become:

$$-\tfrac{1}{2}\sigma_r,\ \tfrac{1}{2}\sigma_\phi,\ \tfrac{1}{2}(\sigma_r - \sigma_\phi),$$

i.e.,

$$-\frac{Ea}{1-\nu}\cdot\frac{1}{2r^2}\left\{\frac{r^2-b^2}{B^2-b^2}\cdot Q(B) - Q(r)\right\} \quad . \quad . \quad . \quad . \quad . \quad (13)$$

$$\frac{Ea}{1-\nu}\cdot\frac{1}{2r^2}\left\{\frac{r^2+b^2}{B^2-b^2}\cdot Q(B) + Q(r) - r^2\theta\right\} \quad . \quad . \quad . \quad (14)$$

$$-\frac{Ea}{1-\nu}\cdot\frac{1}{2r^2}\left\{\frac{2b^2}{B^2-b^2}\cdot Q(B) + 2Q(r) - r^2\theta\right\} \quad . \quad . \quad (15)$$

Equations (10) to (15) give us the complete solution to our problem for the case of a perfectly elastic mould. It is necessary only to evaluate the function $Q(r)$ for the particular temperature distribution assumed.

Temperature Equations.

The temperature distribution in ingot and mould has been calculated by Saitô [3] and the equations he derived have been applied to certain practical cases by Russell.[4] The work of these investigators has been used as the basis of the present stress calculations. Whilst the equations are dependent on some rather sweeping assumptions, Russell's work shows that Saitô's equations give sufficiently good agreement with experiment to serve as a reasonable basis for the calculation of stresses.

The temperature equation derived by Saitô is:

$$\theta = \theta_0 \sum_{n=1}^{n=\infty} A_n' e^{-\frac{\mu_n^2 a^2 t}{B^2}} J_0\left(\frac{\mu_n r}{B}\right) \quad . \quad . \quad . \quad . \quad (16)$$

The large amount of arithmetical work involved in calculating stresses in thin moulds, particularly for small values of time, makes it desirable to find an approximate formula which will be valid for these conditions. The method of approach is as follows: At the instant at which the liquid steel comes into contact with the cold mould surface, the interface instantaneously attains a temperature half-way between the original temperature of the mould and that of the liquid steel. If both the steel and the mould were of infinite extent and the interface were plane, the temperature would remain indefinitely at this value. Fig. 2 shows that the interface temperature calculated on Saitô's formula remains within 5% of this value throughout the period during which the stresses are greatest. It is therefore assumed that the temperature distribution within the mould is the same as that in an infinite slab of the same thickness as the mould, when one surface of the slab is raised at zero time to a temperature $\theta_0/2$ and maintained at that temperature indefinitely. The other surface of the slab is assumed to lose heat according to Newton's law of cooling, as in Saitô's investigation. The formula for the temperature which is applicable to the infinite slab under the conditions specified is:

$$\theta = \frac{\theta_0}{2}\left\{1 - \frac{hx}{1 + hL} - 4\sum_{n=1}^{n=\infty} \frac{\sin \lambda_n x}{2\lambda_n L - \sin 2\lambda_n L} \cdot e^{-\lambda_n^2 a^2 t}\right\} \quad . \quad (17)$$

where $x = (r - b)$ and $L = B - b$, and λ_n is the nth root of the equation:

$$\tan \lambda L = -\lambda/h.$$

The principal advantage of this formula is that only two terms of the expansion are required compared with twelve terms when the Dini expansion is used. A further benefit is that the interface temperature may be chosen to allow for the difference in the thermal constants of steel and cast iron. The interface temperature (θ_I) is related to the casting temperature (θ_0) by the equation:

$$\frac{\theta_0 - \theta_I}{\theta_I} = \sqrt{\frac{\rho_1 c_1 \kappa_1}{\rho_2 c_2 \kappa_2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

where the suffixes 1 and 2 refer to the iron and the steel respectively. Lightfoot's [13] work shows that the interface temperature also depends on the latent heat of solidification of the steel and hence

account can also be taken of this factor. The values calculated by equations (16) and (17) are compared in Fig. 9. The agreement is seen to be quite sufficiently good for practical purposes while the stresses are greatest.

Stress Calculations.

Equations (10) to (15) give the stresses in terms of the function $Q(r)$, which is the integral $\int_b^r r\theta dr$. The expression (equation 16)

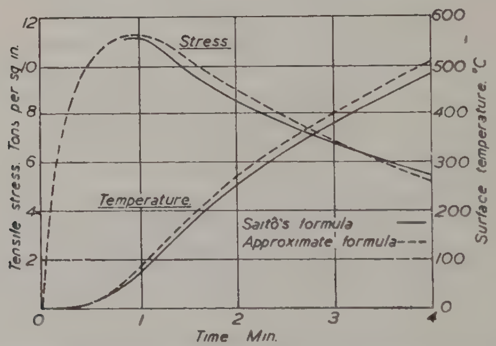

FIG. 9.—Temperature and Stress at the Outer Surface of the Ingot Mould $6\frac{3}{8}$ cm. thick, calculated by the exact and approximate formulæ.

which Saitô derived for the temperature leads to a function $Q(r)$ given by:

$$\theta_0 \int_b^r r \sum_{n=1}^{n=\infty} A_n' \, . \, e^{-\frac{\mu_n^2 a^2 t}{B^2}} J_0\left(\frac{\mu_n r}{B}\right) . \, dr$$

This can be integrated without difficulty and gives:

$$Q(r) = B\theta_0 \sum_{n=1}^{n=\infty} \frac{A_n'}{\mu_n} \cdot e^{-\frac{\mu_n^2 a^2 t}{B^2}} \left\{ rJ_1\left(\frac{\mu_n r}{B}\right) - bJ_1\left(\frac{\mu_n b}{B}\right)\right\} \quad . \quad . \quad (19)$$

When the approximate formula (equation (17)) is used the temperature is expressed in terms of the distance x from the inner mould surface. Thus we write:

$$\begin{aligned} Q(x) &= \int_0^x (b + x)\theta dx \\ &= \frac{\theta_0}{2}\left[bx + \frac{1}{2}\left(1 - \frac{hb}{1 + hL}\right)x^2 - \frac{1}{3} \cdot \frac{h}{1 + hL} \, . \, x^3 + \right. \\ &\left. 4\sum_{n=1}^{n=\infty} \frac{e^{-\lambda_n^2 a^2 t}}{\lambda_n(2\lambda_n L - \sin 2\lambda_n L)} \left\{(b + x)\cos \lambda_n x - \frac{1}{\lambda_n} \sin \lambda_n x - b\right\}\right]. \quad (20) \end{aligned}$$

The instantaneous compressive stresses in the axial and tangential directions at the inner surface at the moment when the metal is poured into the mould are entirely independent of mould conditions. They are the stresses required to restrain completely the expansion of the inner surface, that is, $E\alpha\theta_0/2(1 - \nu)$.

Acknowledgments.

This investigation was carried out under the direction of Mr. D. A. Oliver, Head of the Research Department, Messrs. William Jessop & Sons, Ltd., Brightside Works, Sheffield, who is a Member of the Stresses in Moulds Panel of the Ingot Moulds Sub-Committee. The author wishes to record his thanks to Mr. Oliver and also to Mr. R. H. Myers and Mr. G. Stanfield for their kind interest and encouragement. Thanks are also due to Mr. B. Davison, who critically read the mathematical work, to Mr. C. W. K. Carter, who carried out most of the numerical calculations, and to Mr. J. G. Pearce, Director of the British Cast Iron Research Association, for suggesting typical values for certain physical constants of ingot-mould iron.

SELECTED BIBLIOGRAPHY.

The publications listed below represent only a selection of the relevant literature. Useful bibliographies will be found in references 7, 11 and 12.

(1) First Report of the Ingot Moulds Sub-Committee, p. 143. Seventh Report on the Heterogeneity of Steel Ingots, *Iron and Steel Institute*, 1937, *Special Report No.* 16.
(2) Second Report of the Ingot Moulds Sub-Committee, p. 265. Eighth Report on the Heterogeneity of Steel Ingots, *Iron and Steel Institute*, 1939, *Special Report No.* 25.
(3) S. Saitô : *Science Reports of the Tôhoku Imperial University*, First Series, 1921, vol. 10, Sept., No. 4, p. 305.
(4) T. F. Russell : *Journal of The Iron and Steel Institute*, 1941, No. I., p. 163 P.
(5) D. White : *Welding Journal*, 1940, vol. 19, p. 231-S.
(6) S. Timoshenko : "Theory of Elasticity." New York, 1934 : McGraw-Hill Book Co., Inc.
(7) C. H. Kent : *Transactions of the American Society of Mechanical Engineers, Applied Mechanics Section*, 1931, vol. 53, p. 167.
(8) J. M. C. Duhamel : *Mémoires de l'Institut de France*, 1838, vol. 5, p. 440.
(9) G. Eichelberg : *Forschungsarbeiten auf dem Gebiete des Ingenieurwesens*, 1923, No. 263.
(10) P. Maillard : *Chaleur et Industrie*, 1939, vol. 20, p. 161.
(11) C. H. Lees : *Proceedings of the Royal Society*, 1922, A, vol. 101, p. 411.
(12) B. E. Gatewood : *Philosophical Magazine*, 1941, vol. 32, p. 282.
(13) N. M. H. Lightfoot : Third Report on the Heterogeneity of Steel Ingots, *Journal of The Iron and Steel Institute*, 1929, No. I., p. 364.

A RECORDING DILATOMETER FOR METAL SPECIMENS.*

By L. R. STANTON, M.Sc. (University of Manchester).

Paper No. 7/1942 *of the Alloy Steels Research Committee* (*submitted by Professor F. C. Thompson*).

Summary.

A dilatometer is described which produces a permanent record of the length changes of a metal specimen, with accuracy of 0·001 mm. The range over which measurement can be made extends to about 0·2 mm., the sensitivity being adjusted to suit any particular requirement. The measuring principle involves the tuning of an inductance about its resonant point by means of a small condenser actuated by the dilatometer, and particular care is taken to ensure stability of the apparatus over long periods.

For the purposes of an investigation on the austempering of steels, a recording dilatometer which would measure and record changes in length of the order of 0·001 mm. was required. It was further desired that the apparatus should be suitable for runs of long duration, possibly a week, as well as short runs of an hour or two, and the range of changes of length covered should be fairly great, *viz.*, about 0·2 mm. Broadly, two methods seemed possible: (1) Optical, and (2) electrical.

The former presented considerable difficulties, and attention was, therefore, directed to the second of these methods. After examining the work of Dowling,[1] Lloyd,[2] Prytherch,[3] and Brooke-Smith and Colls,[4] it was decided to carry out work of an experimental nature along these lines, from which the apparatus now to be described was evolved.

The essential principle of the method, which was suggested by Professor F. C. Thompson, consists of the employment of a small double-plate condenser to tune an inductance at, or about, its resonant frequency, thus giving a steep rise or fall of the induced current for very small changes in capacity. The chief drawback to this system in the past appears to have been the tendency of the zero to drift.

Construction of the Dilatometer.

The dilatometer (Fig. 1) consists of a brass table mounted on three Invar legs with levelling screws, on the top of which is mounted

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a micrometer screw B, making four turns to the millimetre; the circumference of the screw is divided into twenty-five parts, so that a rotation of 1 cm. of the periphery causes a vertical displacement of the spindle of 0·01 mm. The spring A, in compression, holds the screw B against its bearing, whether the spindle is being raised or lowered. To the bottom of the micrometer spindle, which projects through a hole in the table, is fixed a short quartz rod, on the lower end of which is a ball-and-socket C which carries the upper plate of the condenser D, used for making the measurements. The lower plate of this condenser is fixed to a quartz tube F, the lower end resting on the cylindrical metal specimen L, and is located centrally by a pin, which fits loosely into the bore of the quartz tube. When

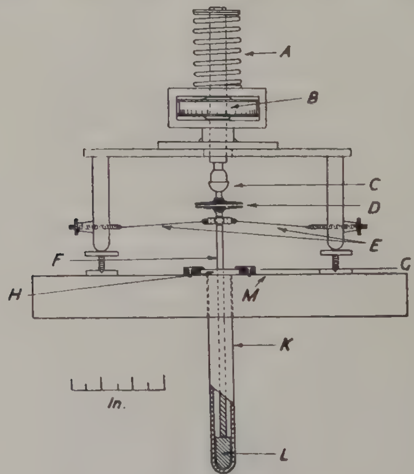

FIG. 1.—The Dilatometer.

the two plates of the condenser are brought into close contact, the ball joint automatically renders them parallel.

The lower condenser plate is centralised by means of the three tension wires E, held by adjustable screws through the legs of the table, leading to a brass collar clamped around the tube F. These wires also exert a slight downward pressure, as the collar is a little higher than the adjusting screws, which serves to maintain a steady contact between the quartz tube and the specimen. It will thus be seen that any alteration in the length of the specimen alters the distance apart of the plates of the condenser D.

The cylindrical specimen (which is to be subjected to heat treatment) has a spherical lower end which stands in the round-bottomed silica tube K, fitting it sufficiently closely to be free from wobble. The upper end of this silica tube ends in a flange H, the under surface of which is ground flat, and is firmly held against the surface M

(which is the upper side of a water-cooled tank) by the collar G. It will be seen then that the specimen is held between contacts which are of very low thermal expansibility, and are approximately self-compensating by reacting in opposite directions.

The electrical circuit * is shown in Fig 2. Short, thin leads from the two condenser plates connect through rigid, well-spaced and firmly supported conductors, to the two ends of the resonant inductance L_2. A pentode screened-grid valve V_1 is used as an oscillator, the frequency being controlled by a quartz oscillator A of frequency about 1000 kilo-cycles per sec., and having a temperature stability of 20 parts in a million per degree centigrade. The circuit used is such as to provide considerable stability as regards

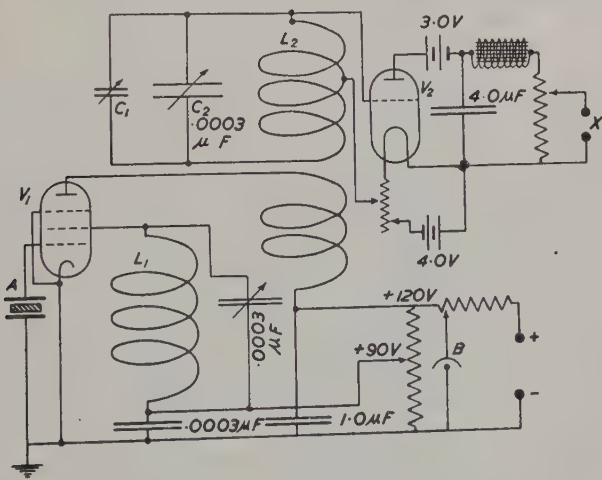

FIG. 2.—The Electrical Circuit.

the amplitude of the oscillations generated, as well as the frequency, and the high-tension supply is regulated by a neon stabiliser B. The cathode of the pentode is indirectly heated, and its temperature has been found to be practically unaffected by small momentary voltage fluctuations.

The output of the oscillator is taken from a small number of turns made in the anode lead, to which the inductance L_2 is very loosely coupled, and the position of the two coils is so arranged as to prevent any alteration in the degree of coupling.

The inductance L_2 is tuned very nearly to its resonant frequency by the adjusting condenser C_2, in parallel with the measuring condenser C_1. The output of this coil affords the current which ultimately acts as a measure of the movement of the measuring con denser. It is imperative that as little load as possible should be put

* Details of the electrical apparatus are given in an Appendix.

on this output. Such output is, therefore, taken from a tapping from the inductance L_2, of only a few turns, and this is applied to the anode of a rectifying valve V_2 arranged to work as a Moullin[5] valve voltmeter, with slight modifications mentioned below.

After passing a filter circuit consisting of a choke and condenser, the rectified current flows through a potentiometer, and is then applied to a potentiometer-type Kent recorder at X.

The Moullin voltmeter has the advantage of requiring no separate high-tension supply for operation; it was found, however, to be unsatisfactory for use with the Kent recorder, as the potential of the output was not high enough. Accordingly the circuit was modified by the introduction of a 3·0-V. positive potential applied to the anode, and supplied by two large-capacity dry cells.

Operation of the Dilatometer.

The specimen being in position, and the condenser plates adjusted so as to be strictly parallel, they are set about 1·0 mm. apart. The adjusting condenser C_2 is set so that any further *increase* in capacity results in a fall in the current output. This means that when the specimen expands, and the measuring condenser plates approach each other, the reading of the galvanometer *falls*. The reason for this is to get as great a degree of linearity of the galvanometer-reading/distance curve as possible, since the sensitivity of the measuring condenser falls as the plates move apart, while the change of current flowing in the resonant inductance increases as the resonant frequency is approached. Adjustment of the potentiometer across the output of the valve voltmeter permits the zero position to be adjusted, within limits, on the galvanometer chart.

The desired degree of sensitivity of the apparatus is finally adjusted by altering the mean position of the measuring condenser, and bringing the galvanometer pen back to a high reading by means of the adjusting condenser.

Different degrees of sensitivity of the apparatus can be obtained by the use of condenser plates of different size, as well as by altering their mean distance apart.

Calibration.

When a satisfactory mean distance apart of the plates of C_1 has been found, the galvanometer pen is brought to its maximum reading by raising the micrometer screw.

The micrometer is then screwed down in equal, suitable known steps, the galvanometer reading being recorded at each of these points. From this the calibration curve may be constructed. Repeated calibrations have been made, which agree to within 0·0001 mm., with a sensitivity of the apparatus of 0·01 mm. displacement equal to 0·5 in. on the galvanometer scale, a magnification of

about 1300. Over a range of 0·06 mm., with the above sensitivity, straight-line calibrations have been obtained. Beyond this range the curve tends to bend at each end.

Stability of the instrument has been obtained by the quartz-crystal control of the frequency, by using single-layer inductances wound with high-gauge wire, by control of the high-tension supply to the oscillator, and by rigid wide-spacing of the leads. Control is maintained by a milliammeter in the output circuit of the oscillator, and in the anode circuit of the valve voltmeter.

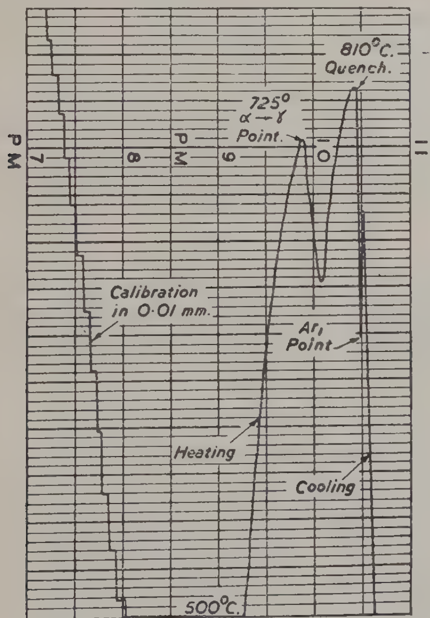

FIG. 3.—Tracing of a Specimen Record.

The chart used in the present instance is 10 in. wide. As an example of the higher magnification possible, using condenser plates 4·0 cm. in dia. in their most sensitive position, *i.e.*, about 0·001 in. apart, a deflection of 6·0 in. can be obtained when the condenser opens 0·015 mm.; this permits of readings being made with ease to within 0·0001 mm., giving a magnification of about 10,000.

Over a period of 12 hr., from 11.0 P.M. to 11.0 A.M., the drift amounted to only such a quantity as would represent a movement of the condenser plates of 0·01 mm., notwithstanding an atmospheric temperature variation of 12° C. No attempt at temperature control of the oscillator and connections has been made, except that the entire oscillator circuit, excluding the anode coil, is contained in a

copper-lined box, primarily intended for purposes of electrical shielding. The inductance L_1 is separately screened.

Dilatometers using capacity changes as the controlling device often employ a cathode-ray oscilloscope as the indicator in a null circuit. The recording galvanometer has important advantages, which at least compensate for a possibly slightly lower degree of sensitivity. While the cathode-ray tube fulfills more completely the requirement that no load shall be put on the resonant circuit, it is practically impossible to take readings sufficiently often and accurately to show a true picture of what is happening during the critical changes of the steel; over long periods there are obvious difficulties. The present method gives readings every two seconds, and, of course, provides a permanent record.

Such a record is shown in Fig. 3. It refers to the heating of a $\frac{7}{8}$-in. long steel specimen to 810° C., the contraction due to the $\alpha \rightarrow \gamma$ transformation being very clearly shown. This was followed by the curve for a fairly rapid cooling, in which the Ar_1 point is well revealed. Alongside are shown the steps of the calibration in 0·01 mm.

The author's thanks are due to Professor F. C. Thompson, and to Dr. J. W. Cuthbertson for many helpful suggestions; also to the Alloys Steels Research Committee for the financial assistance which enabled this work to be carried out.

REFERENCES.

(1) DOWLING : *Scientific Proceedings of the Royal Dublin Society*, 1921, vol. 16, p. 175.
(2) LLOYD : *Journal of Scientific Instruments*, 1929, vol. 6, p. 81.
(3) PRYTHERCH : *Journal of Scientific Instruments*, 1932, vol. 9, p. 128.
(4) BROOKE-SMITH and COLLS : *Journal of Scientific Instruments*, 1939, vol. 16, p. 361.
(5) MOULLIN : "Radio Frequency Measurements." London, 1926 : Chas. Griffin & Co., Ltd.

APPENDIX.—*Constructional Details of the Electrical Apparatus.*

The two coils L_1 and L_2 consist of 4-in. dia. paxolin formers, wound with 18-gauge double-cotton-covered copper wire, shellacked and baked to dry. Both contain an identical number of turns, *viz.*, 65, and the number of turns tapped off to the valve voltmeter is 25.

The oscillator is contained in a wooden box with a lid, both lined with stiff copper sheet, and the variable condenser tuning the oscillator can be manipulated by a rod projecting through a hole in the lid.

Both variable condensers are of good commercial quality, fitted with slow-motion dials. The coil in the anode circuit of the oscillator, which excites L_2, is wound on a short length of $4\frac{1}{2}$-in. dia. former, and is screwed firmly to the side of the box, outside it. L_2 is held

rigidly against this, both axes being in line, the windings of the two coils being 1 in. apart. There are 24 turns on the anode coil, this number being found by trial and error to give the desired excitement to L_2.

The quartz crystal is between two flat aluminium discs, resting on the lower one, and separated from the upper one by means of silica rods, leaving a gap of about 0·007 in. between the upper surface of the crystal and the upper plate.

The high-tension supply to the oscillator is provided by a commercial "eliminator," employing copper-oxide rectification, and giving about 30 m.amp. at 150 V. This is reduced and controlled at 120 V. by the neon tube.

The potential divider consists of a number of small radio resistances connected together, totalling 1·5 megohms.

The remainder of the resistances, variable and fixed, and the fixed condensers are the usual type of radio component.

The valve V_1 is a Cossor M.S. Pen.B., and V_2 is any ordinary 2-V. detector valve.

THE INFLUENCE OF TEMPERATURE ON THE MODULUS OF ELASTICITY OF SOME PLAIN CARBON AND ALLOY STEELS.*

By G. C. SEAGER, Ph.D., and F. C. THOMPSON, D.Met.
(The University of Manchester).

Paper No. 9/1943 *of the Alloy Steels Research Committee.*

Summary.

The variation of Young's modulus with temperature has been measured for a series of steels, both plain carbon and alloyed, using an interferometer of high sensitivity. It is shown that the curves are not smooth but have abnormalities which just exceed the experimental error.

Although a very large amount of work has been done on the change of the modulus of elasticity of steels as the temperature is raised, from which some suggestion has been obtained that the curves are not smooth, the sensitivity of the methods employed has not been sufficiently great nor have the temperature intervals been sufficiently small to enable one to say with certainty whether the abnormalities found in other mechanical properties exist also in respect of this.

It was decided, therefore, to carry out measurements on a series of steels, both plain carbon and alloyed, using apparatus of the highest available sensitivity, determinations of the modulus being made every 2–3° C.

Apparatus.

An apparatus for the accurate determination of this value, both at room and at elevated temperatures, has been described by

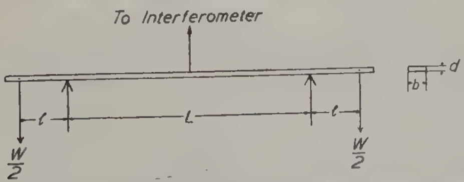

Fig. 1.—Diagrammatic Representation of Cuthbertson's Apparatus for Measuring the Modulus of Elasticity.

J. W. Cuthbertson.[1] The test-piece, in the form of a flat strip, is supported on two knife-edges, L cm. apart, as indicated in Fig. 1,

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loads of $\frac{1}{2}W$ being applied at a distance l from each knife-edge. The deflection δ at the centre of the bar is measured with an interferometer, the modulus of elasticity of the metal being given by the formula :

$$E = \frac{WlL^2}{16\delta I},$$

where I is the moment of inertia of the cross-section of the bar, *i.e.*, $bd^3/12$.

Results obtained with this apparatus for the elastic properties of some anti-friction alloys were given in a later paper by the same author,(2) but it soon became clear that for use with steels an appreciable increase in the sensitivity would be necessary. This could only be obtained by increasing δ or by improving the accuracy with which it could be measured. Since the measurements were already being made to a fraction of a wave-length, it was decided to increase the length and decrease the thickness of the specimen. A new pair of knife-edges was constructed, 3·75 in. apart, l being maintained as before at 0·75 in., the total length of the test-piece being increased from 3 to 5·25 in. In this way, the deflection for a given stress was increased 6·25 times. By reducing the thickness of the strip from 0·12 in. to 0·0625 in., the value of δ was approximately doubled again.

These modifications meant that it would be necessary to count some 2000 fringes for each determination, and it was primarily in order to avoid this that the method of using the apparatus to be described was devised.

If a wedge-shaped film of air is enclosed between two plane glass plates, the linear interference fringes formed will be parallel to the line of intersection; and, whereas if one plate be tilted about an axis parallel to this line the fringes will appear to move together in a direction at right angles to their length, if the plate be tilted about an axis which is not parallel to this line, the whole fringe system will appear to rotate with the line of intersection of the two planes.

In particular, if the axis about which the plate is tilted is perpendicular to the original line of intersection of the two planes, and lies in the plane of the tilting plate, the rotation of the fringes is given by :

$$\tan \alpha = \frac{\tan \phi}{\sin \theta},$$

where α is the angle through which the fringes rotate, θ is the original wedge angle, and ϕ is the angle through which one of the mirrors is tilted about an axis making an angle θ with the surface of the other mirror, and perpendicular to the original fringes. In practice, if θ is of the order of $6'$, tilting the moving mirror through $1'$ rotates the fringe system through about $10°$.

In the interferometer the lower mirror rested upon three pins,

two of which were rigidly supported, while the third was carried on the end of a 10-S.W.G. Invar rod, the lower end of which rested on the centre of the test-piece. If the mirrors were set to give fringes perpendicular to the line joining the two fixed pins (in which position the fringes appeared horizontal in the microscope), observing whether the fringes remained parallel to a fixed cross-wire in the microscope eye-piece gave a very sensitive method of detecting small changes in the tilt of the lower mirror, and, therefore, of detecting the bending of the test-piece.

Once the lower mirror has tilted through an angle of about 5′ (corresponding to a rotation of the fringes through 42°) $d\alpha/d\phi$ rapidly decreases. If, now, the upper mirror is also tilted through the same angle, the fringes will again become horizontal. The apparatus is, therefore, arranged so that the upper mirror can be tilted through a small but constant angle, say, 1°. The load on the test-piece is then increased until the fringes appear horizontal (the cross-wire in the eye-piece of the microscope enables this point to be determined with considerable accuracy). This gives the value of W for a definite, constant value of δ, and determinations of W made in this way for the same value of δ will clearly be proportional to the elastic modulus.

The modified apparatus is illustrated diagrammatically in Fig. 2. M_1 and M_2 are the interferometer mirrors (M_1 being the upper—

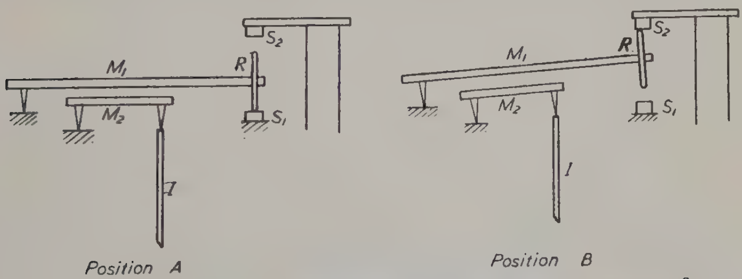


FIG. 2.—Diagrammatic Representation of the Modified Apparatus for Measuring the Modulus of Elasticity.

half-silvered—mirror, and M_2 the lower), and I is the Invar rod resting on the centre of the test-piece. R is an aluminium rod, about $1\frac{1}{4}$ in. long, carried at one end of the frame carrying the mirror M_1 but free to move longitudinally by means of a fine screw adjustment. R normally rests against the fixed stop S_1, but M_1 can be tilted so as to bring the upper end of R against the stop S_2, the position of which can be adjusted vertically by means of a $\frac{1}{4}$-mm. pitch screw. In this way the actual position of M_1 when R is resting against either stop can be adjusted by moving R without affecting the angle through which it can be tilted, which is controlled by the position of S_2.

A suitable position for S_2 is found by trial, and is then kept constant throughout the range of tests which it is desired to carry out with any particular specimen.

With R resting on S_1 the mirrors are adjusted to give horizontal fringes, parallel to the cross-wire in the observing microscope. Mirror M_1 is then tilted until R comes in contact with S_2. The load—partly in the form of brass weights and partly of water in a beaker—is then applied to the ends of the test-piece, the bending of which causes M_2 to tilt, and by increasing the load—by running water into the beaker from a burette—until the fringes are again horizontal, W (in the formula given above) can be adjusted to give the set value of δ to within one part in 2000.

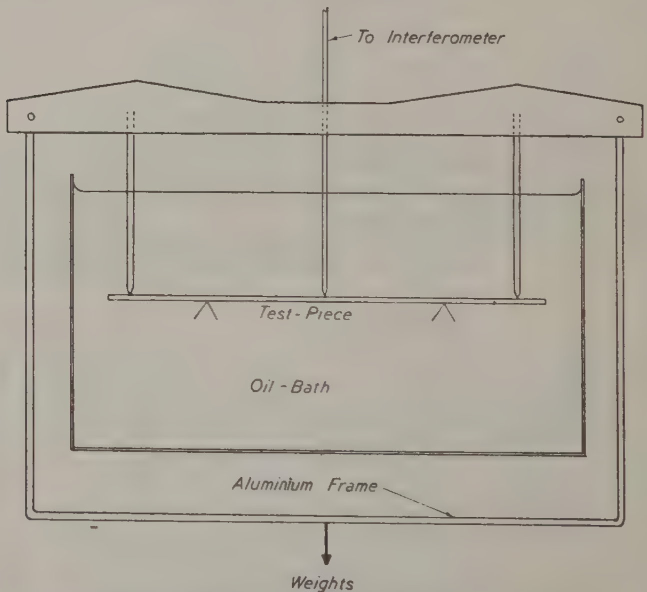


FIG. 3.—Framework for carrying the Load.

At each temperature at which such a determination is made it is necessary, owing to the expansion of various parts of the apparatus as the oil-bath heats up, first to adjust the position of R to give horizontal fringes with no load on the test-piece.

In place of the original lever arrangement for applying the load to the ends of the test-piece, an aluminium frame was made for this work which passed completely round the outside of the oil-bath; the weights were hung from the bottom cross-piece of this, while pointed rods fixed to the top cross-beam rested in the centre-punch marks at the ends of the test-piece, as shown in Fig. 3.

Partly in order to secure smoother operation and partly to

reduce the time required to take a reading, an automatic arrangement for applying and removing the load was fitted. This is illustrated in the "load off" and "load on" positions in Fig. 4, (*a*) and (*b*). The weight of the load is normally taken by a hori-

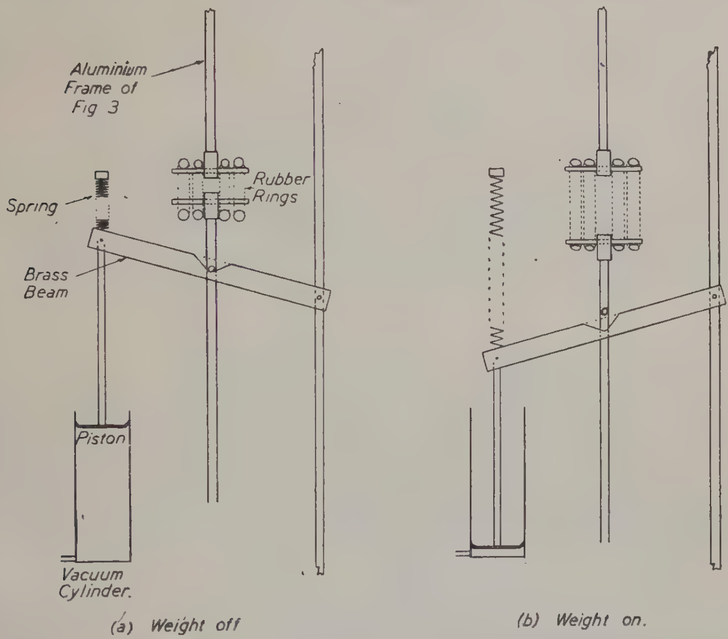


FIG. 4.—Automatic Arrangement for Applying and Removing the Load.

zontal brass beam, pivoted at one end and supported at the other end by springs. This can be pulled down against the action of the springs by means of a piston and cylinder—the piston being sucked into the cylinder by connecting the latter to a simple filter pump and vacuum reservoir—leaving the load hanging from rubber rings carried by the aluminium frame described above. A similar arrangement was fitted to move the mirror M_1 from the horizontal to the tilted position, both being controlled by the same two-way tap. In this way it was possible to determine the required value of W in 30–40 sec. and to take readings every 3° C. as the oil-bath and test-piece cooled from 250° C.

Other, minor, alterations made to the apparatus included the fitting of a delicately pivoted, weighted lever, in place of springs, to counterbalance the weight of the Invar rod resting on the centre of the test-piece, the fitting of a jewel bearing cup to the upper end of this rod, into which the pin of the lower mirror table was lightly pressed by means of a small spring, and the fitting of a

spring clip to its lower end to hold the pointed rod firmly against the test-piece. These modifications were made necessary by the increase in the deflection of the test-piece and in the corresponding movement of the Invar rod and lower mirror, which resulted in the movements of the test-piece not being accurately followed by the interferometer. With the shorter and thicker test-pieces of the tin alloys for which the apparatus was originally designed such difficulty was not experienced, and the simpler arrangement of these parts was then perfectly satisfactory.

It should be stressed that the accuracy of one part in 2000 claimed applies only to the relative values of the moduli of elasticity at the various temperatures, and not to their actual values in any particular units. One of these temperatures may, of course, be room temperature, at which the value of the modulus may be known or may be determined separately, from which value that at any of the other temperatures may easily be calculated.

Consideration of Possible Errors.

The error introduced in the determinations at elevated temperatures due to the changes in the dimensions of the heated test-piece was considered by Cuthbertson in his work on anti-friction alloys, but no correction was then applied. With the present steel test-pieces, if it is assumed that the expansion of the steel block carrying the knife-edges is the same as that of the test-piece, the correction for thermal expansion is given by :

$$E = E'(1 - \alpha t),$$

where E is the true modulus of elasticity at temperature $t°$ C. and E' is the apparent modulus calculated from :

$$E' = \frac{WlL^2}{16\delta I},$$

the measurements of the test-piece being made at room temperature (or more strictly at $t = 0°$ C.). If the coefficient of expansion of steel is taken as 11×10^{-6} this correction amounts to about 0·27% for a temperature rise of 250° C. This error has not been taken into consideration in this work. If, however, the value of the modulus at some elevated temperature is required *in terms of the dimensions of the test-piece at that temperature* it is only necessary to multiply the value obtained from Table III. by $(1 - \alpha t)$.

Since the measured value of the modulus of elasticity is dependent upon the coefficient of thermal expansion of the material, it is, of course, possible that the discontinuities noted in the modulus/temperature curve might be due to discontinuities in the thermal-expansion/temperature relationship. Calculation shows, however, that to account for the irregularity noted at 120° C. in steel No. 1—one of the smallest of the irregularities greater than the possible

experimental error—a change of over 100% in the coefficient of expansion would be necessary. It would, therefore, appear improbable that this is the true explanation.

A further way in which thermal expansion may influence the result lies in the difference between adiabatic and isothermal elasticity. The relationship between the two is given by : *

$$\frac{E_t}{E_\phi} = 1 - \frac{\alpha t E_t}{\rho C_T},$$

where E_t = modulus of isothermal elasticity,
E_ϕ = modulus of adiabatic elasticity,
α = coefficient of thermal expansion,
ρ = density,
C_T = specific heat (at constant temperature),
t = temperature (absolute).

If we put :

$E_t = 30 \times 10^6$ lb. per sq. in. $= 2{\cdot}1 \times 10^{12}$ dynes per sq. cm.,
$\alpha = 11 \times 10^{-6}$,
$\rho = 7{\cdot}8$ g. per c.c.,
$C_T = 0{\cdot}107$ cal. per g. $= 0{\cdot}107 \times 4{\cdot}18 \times 10^7$ ergs per g. per ° C.,
$t = 293°$ K. (20° C.),

we then have :

$$\frac{E_t}{E_\phi} = 1 - 0{\cdot}002$$

i.e., E_ϕ is about 2 parts in 1000 greater than E_t, rising to about 3 parts in 1000 at 200° C. The difference between the two elasticities is, therefore, of the same order as the discontinuities shown in the curves in Fig. 6. It might be suggested, therefore, that they were due to differences in the time taken for the determinations to be made at each temperature, resulting in isothermal conditions being more nearly established in some cases than in others, with a consequent variation in the measured modulus.

When the modulus of elasticity is determined by measuring the effect on the length of a test-piece of a simple direct tensile or compressive stress, some time may be required for the establishment of isothermal conditions, since it is necessary for the test-piece to come into thermal equilibrium with the surrounding air. When a bend test is used, however, one surface of the test-piece is extended and, therefore, cooled, while the other is compressed and heated. The heat flow across the relatively small thickness of the test-piece quickly restores a condition of thermal equilibrium. It would, therefore, be expected that isothermal conditions would be established comparatively rapidly in this case, and this has been confirmed by experiment. Immediately after the load has been applied there is a very slight gradual increase in the deflection of the centre of the test-piece lasting for $1\frac{1}{2}$–2 sec. It is, however, very slight compared with that theoretically to be expected, and probably represents the very end of the change from adiabatic to

* *See*, for example, Searle.(3)

isothermal conditions, the greater part of the change having already occurred during the time required to apply the load smoothly. A considerably greater time than this normally elapses before the completion of the reading, and it may, therefore, be assumed that isothermal conditions have been fully established.

The possibility of errors being introduced into the readings by the heating of the interferometer by hot air from the oil-bath has also been considered. If the oil-bath is heated rapidly to, say, 230° C. and the modulus of elasticity measured immediately, the result obtained does not change if the bath is kept at that temperature for, say, 1–2 hr., although the interferometer may warm up appreciably during that time. Further, if the oil-bath is heated from room temperature to, say, 140° C. and the modulus measured, the result is the same as that obtained if the oil-bath were held for some time at 250° C. and then cooled down to 140° C., although in the latter case the interferometer may be appreciably warmer. It may, therefore, be assumed that such an effect, if present, may be neglected.

One other factor remains to be considered, namely, the effect of the anticlastic curvature (the deformation of the cross-section of the beam). In the case of thin steel beams the effect of this on the deflection may amount to as much as 10%, the curvature $(1/\rho)$ produced by a bending moment M being given by :

$$M = \frac{EI}{\rho} \cdot \frac{m^2}{m^2 - 1}, \text{ where } \frac{1}{m} = \text{Poisson's ratio},$$

instead of the more usual equation :

$$M = \frac{EI}{\rho}$$

applicable to thick beams. The terms "thin" and "thick," however, being purely relative, it is important to determine the magnitude of the effect in the present instance.

Timoshenko [4] has given a method of calculating the correction to be applied in cases intermediate between the two given above, from which it appears that the correction in the present instance amounts to less than one part in 10,000, and has, therefore, been neglected.

Results.

Many earlier workers [12] have noted discontinuities in the elastic properties of steel at comparatively low temperatures. Chevenard,[5] in 1922, obtained a relative modulus curve showing an inflection at about 210° C., and Lea [6] a discontinuity at 220–230° C. in the torsional-rigidity/temperature curve for a mild steel. In the following year Goffey and Thompson [7] showed the existence of a number of discontinuities in the torsional-elastic-limit/temperature curves for iron and plain carbon steels, confirmed more recently by Marshall and Thompson.[8] The greater part of the

work on the variation of Young's modulus with temperature has, however, been carried out at temperature intervals too great for it to be possible to say whether such discontinuities are present in this case also.

Three plain carbon steels and four alloy steels were selected for test, their analyses being given in Table I. A specimen cut from Armco iron strip cold-rolled and annealed was also tested.

TABLE I.—*Analyses of Steels Used.*

Steel No.:	1.	2.	3.	4.	4(*a*).	5.	6.
Carbon. %	0·18	0·45	0·77	0·12	0·12	0·27	0·20
Silicon. %	0·065	0·141	0·136	0·7	0·7	0·27	0·16
Manganese. %	0·8	0·68	0·62	0·3	0·3	0·22	0·51
Sulphur. %	0·08	0·141	0·138	...	...	0·011	0·010
Phosphorus. %	0·025	0·035	0·032	...	...	0·015	0·012
Nickel. %	...	...	...	8·0	8·0	0·029	3·10
Chromium. %	...	...	...	18·0	18·0	13·22	Trace
Treatment	Hot-rolled	An-nealed	An-nealed	Softened	Steel 4 cold-rolled (Brinell hardness ☰ 375)	An-nealed	An-nealed

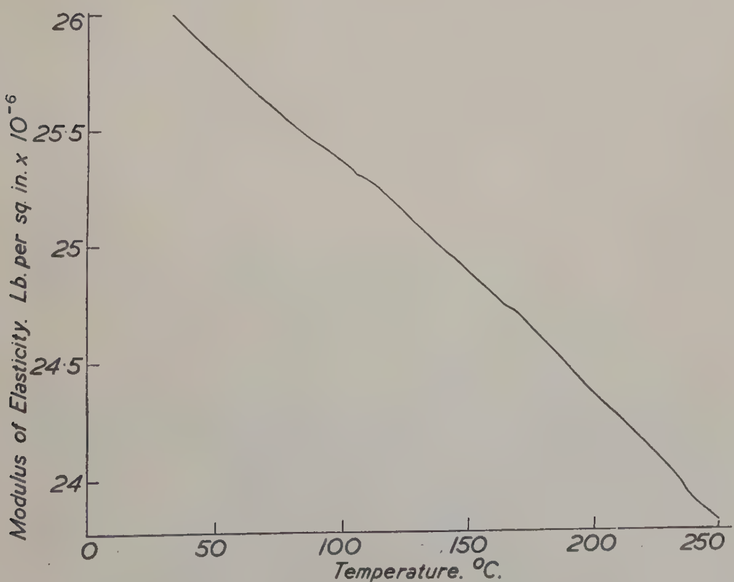


FIG. 5.—Modulus of Elasticity Curve for Armco Iron.

Three or more sets of determinations were made on each specimen, the results plotted and the three curves averaged; a mean

curve was then plotted. Although all the steels except one were in the soft condition, it was found necessary after preparing the test-piece to hold it for some hours at 200–250° C. Even then the results obtained on the first—and sometimes also on the second—cooling had to be discarded, the next three or more—which, in general, showed good agreement—being treated as mentioned above. The reproduction of such curves, which had necessarily to be plotted to a large scale, is difficult, the actual points obtained being too closely spaced to show in Figs. 5 to 12.

The first discontinuity in the curve for Armco iron, Fig. 5, consists of a " step " in the curve at 110° C., and a second step occurs between 160° and 170° C. There is also a slight " dip " in the curve in the region of 240° C.

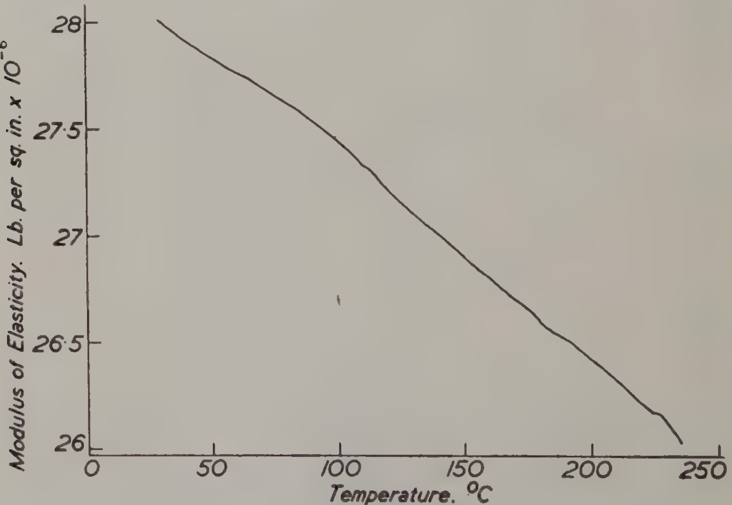


Fig. 6.—Modulus of Elasticity Curve for Steel 1.

Steel No. 1 (0·18% carbon), Fig. 6, shows a marked irregularity between 110° and 120° C., after which, with the exception of a slight dip at 180° C. the existence of which is doubtful, there is nothing of note until a distinct step is reached a little above 220° C.

The first irregularity in the curve for steel No. 2 (0·45% carbon), Fig. 7, occurs at a rather lower temperature, being between 100° and 110° C.; a second, very slight, dip is found between 130° and 140° C., and again a marked step rather above 220° C.

In the case of steel No. 3 (0·77% carbon), Fig. 8, there is a peak just above 120° C., a second, less distinct, at 135° C., and a marked change of slope at about 230° C.

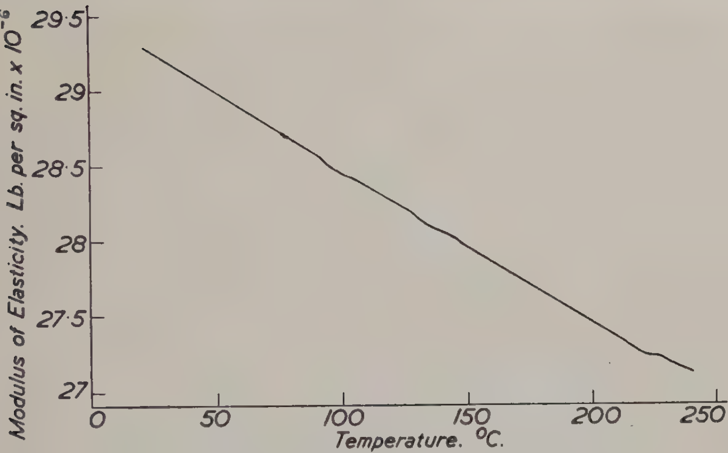


Fig. 7.—Modulus of Elasticity Curve for Steel 2.

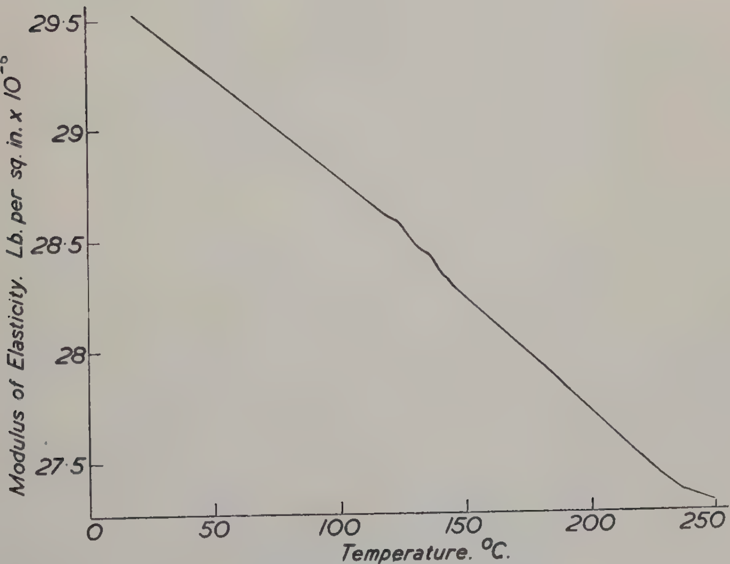


Fig. 8.—Modulus of Elasticity Curve for Steel 3.

There is a pronounced dip in the curve, Fig. 9, for steel No. 4 (softened 18/8 stainless steel) between 100° and 110° C., a change of slope at 160° C., and a further slight dip at 220° C. The same

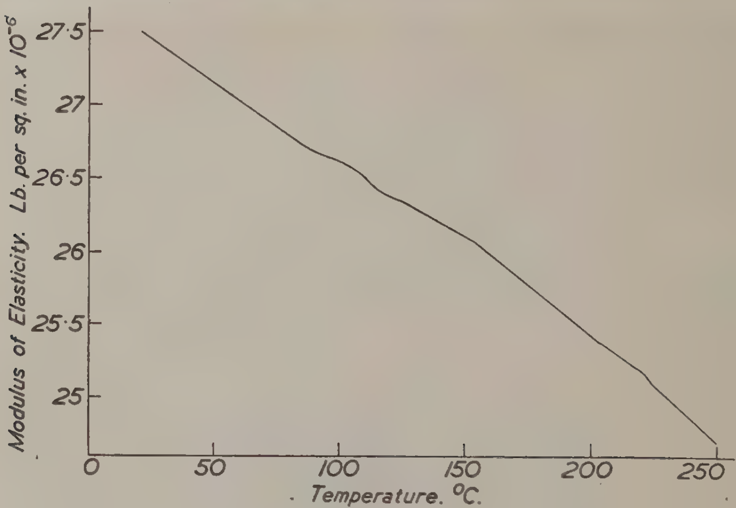


FIG. 9.—Modulus of Elasticity Curve for Steel 4.

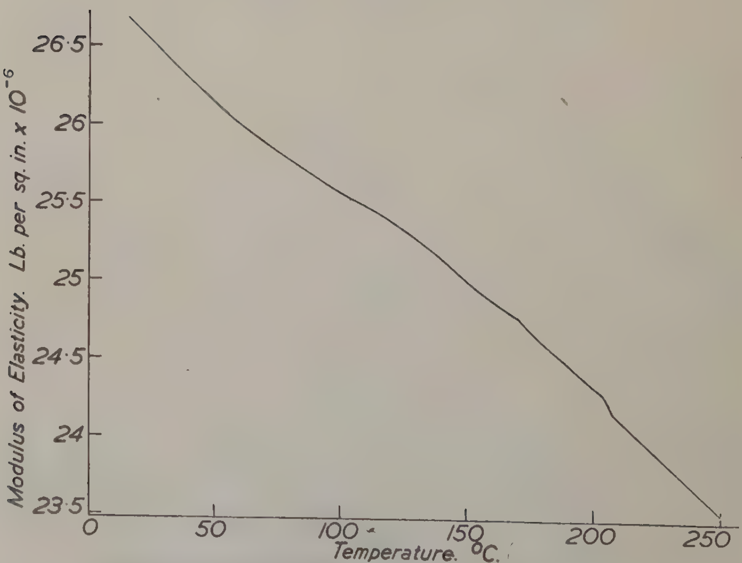


FIG. 10.—Modulus of Elasticity Curve for Steel 4(*a*).

steel in the cold-rolled state (No. 4 (*a*)), Fig. 10, shows no discontinuities with the exception of a slight peak at 165–170° C. and a definite step between 205° and 210° C.

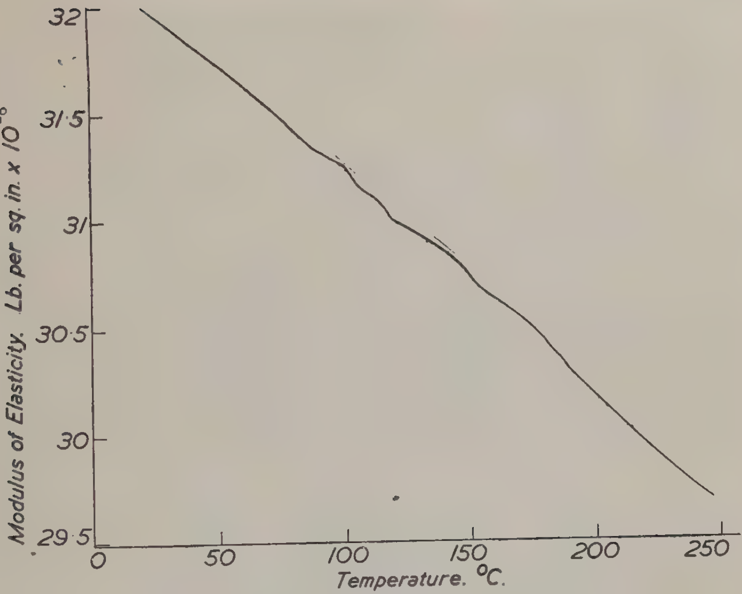


FIG. 11.—Modulus of Elasticity Curve for Steel 5.

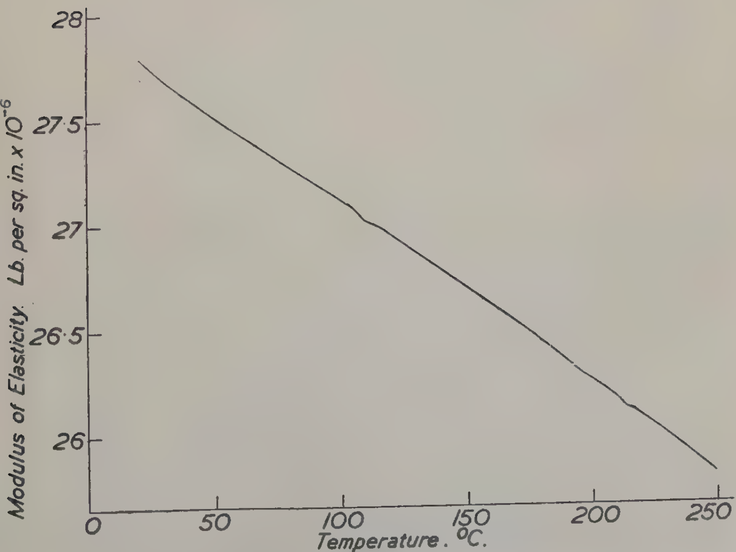
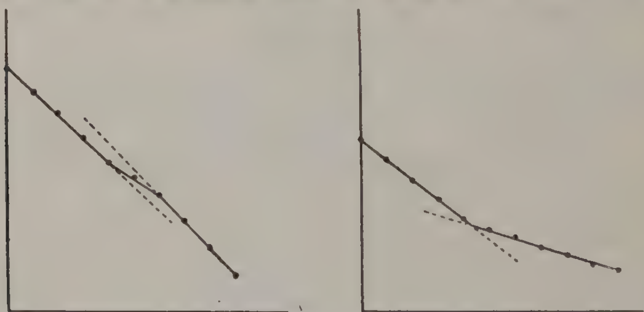


FIG. 12.—Modulus of Elasticity Curve for Steel 6.

Steel No. 5, Fig. 11, a 13% chromium stainless steel, shows a number of very marked irregularities. A step at 100° C. is followed by a dip leading to a second step at 115° C.; a further dip occurs at 155° C., after which the curve is smooth within the limits of experimental error.

The 3% nickel steel, Fig. 12, gives a very smooth curve with the exception of two dips, the first at 110° C., the second at 215° C.

The terms " dip " and " step " have been used repeatedly above and may require further explanation. By a " dip " is meant a discontinuity in which the portions of the curve on either side are colinear, by a " step " a discontinuity in which the two curves are parallel but not colinear. In the case of a dip, if no determinations had been made at the exact temperature at which it occurs, it would have escaped detection. In the case of a step, however, smooth curves drawn through the points on either side would not meet. Typical examples of a step and of a change of slope are shown on a much enlarged scale in Fig. 13. For con-



(a) Typical "step" change. (b) Change of slope

FIG. 13.—Typical Examples of a " Step " and a Change of Slope on an enlarged scale.

venience the temperatures of the discontinuities noted with the various steels are collected in Table II., together with their magnitudes—the deviations from the smooth curves being expressed as a percentage of the value of the elastic modulus at that temperature.

The magnitudes of these discontinuities are very small compared with those obtained by other workers on other elastic properties; nevertheless they are—with the possible exception of the 180° C. point in steel No. 1—too great to be accounted for by experimental error, the deviation from the smooth curve being in some cases as much as five times as great as could be accounted for in this way. Furthermore, they are not dependent upon the evidence of one particular determination or even of a series of determinations made at one particular temperature, the points on each side, as Fig. 13 clearly shows, definitely " leading up " to the discontinuity recorded.

In general, the points appear to be grouped around three tem-

TABLE II.—*Temperatures and Magnitude of Discontinuities in Modulus of Elasticity Curves.*

Steel No.	Temp. ° C.	Deviation. %.	Temp. ° C.	Deviation. %.	Temp. ° C.	Deviation. %.
Armco iron	110	0·10	160–170	0·13	240	0·19
1	110–120	0·08	180	0·05	220	0·13
2	100–110	0·09	130–140	0·07	220	0·17
3	120	0·14	130–140	0·07	230	...*
4	105	0·16	160	...†	220	0·14
4(*a*)	...	...	165–170	0·10	205–210	0·27
5	95–100	0·23	155	0·13	...	...
	115	0·17				
6	110	0·09	...	...	215	0·07

* Slope of curve decreases by 60%.
† Slope of curve increases by 40%.

perature regions, the first about 110–120° C., the second 160–170° C. and the third in the region around 220–230° C. It would appear significant that the change points found by Goffey and Thompson,(7) from measurements of the torsional elastic limit, were given as 120°, 170° and 230° C. (considering only those points lying between 90° and 250° C.). Chevenard (5) gave 210° C. as a point of inflection in the elastic-modulus/temperature curve, and associated this with the magnetic transformation of cementite. As will be seen from Table II., however, this point is present even in the case of Armco iron and the austenitic 18/8 stainless steel.

The effect of cold-rolling in suppressing the lowest of the three points in the case of steel No. 4 is in accord with the results of Marshall and Thompson,(8) who found that cold-working had a tendency to smooth out the discontinuities in the torsional-elastic-limit/temperature curve.

The Thermo-elastic Coefficient.

Although the above measurements are purely relative, it is possible to calculate an accurate value for the thermo-elastic coefficient from the curves obtained.

For the purpose of this paper, the thermo-elastic coefficient may be defined as the coefficient α in the equation :

$$E_t = E_0(1 + \alpha t)$$

where E_0 = modulus of elasticity at 0° C.,
and E_t = modulus of elasticity at t° C.

This assumes the graph connecting E_t with t to be linear. In most of the curves obtained, however, the rate of fall of the modulus of elasticity with increase of temperature increased slightly as the temperature rose, but the error introduced by neglecting this and taking a mean linear relationship between 0° and 250° C. is small and is given, together with the values of α for the various steels, in Table III.

TABLE III.—*Thermo-elastic Coefficient α and Maximum Error in* E_t.

Steel No.	Thermo-elastic Coefficient, a.	Max. Error in E_t, assuming Linear Relationship between E_t and t.
Armco iron	-3.86×10^{-4}	0·2%
1	-3.27×10^{-4}	0·25%
2	-3.495×10^{-4}	0·2%
3	-3.27×10^{-4}	0·3%
4	-4.25×10^{-4}	0·4%
4(a)	-4.85×10^{-4}	0·4%
5	-3.10×10^{-4}	0·25%
6	-3.105×10^{-4}	0·15%

A recent publication by Fahlenbrach and Meyer [9] gives the value -2.2×10^{-4} for the thermo-elastic coefficient for "iron" between $-180°$ and $+20°$ C. From data given for the variation of the modulus of elasticity above room temperature, it would appear that the coefficient would be of the order of -3×10^{-4} between 20° and 300° C. In this case, however, the error involved in assuming a linear relationship between elasticity and temperature is much greater—about 2%. Jacquerod and Mügeli [10] give -3.11 to -3.13×10^{-4} as the value for iron and -3.08 to -3.22×10^{-4} for steel over the range 0° to 80° C.

The Modulus of Elasticity at Room Temperature.

It has been stressed that the comparatively high degree of accuracy claimed for these results applies only to the *comparative* values of the modulus. Very careful determinations of the modulus were made at room temperature for each of the steels, using the apparatus as originally designed by Cuthbertson, the results being given in Table IV. The figure for Armco iron may appear abnormally low, but similarly low values for this material have been obtained by other methods of testing.

TABLE IV.—*Modulus of Elasticity at Room Temperature of the Steels Used.*

Steel No.	Modulus of Elasticity. Lb. per sq. in.	Temp. of Testing. ° C.	Max. Range of Stress. Lb. per sq. in.
Armco iron	26.2×10^6	19·5	7000
1	28.1×10^6 *	20	6000
2	29.3×10^6	21	5400
3	29.5×10^6	21	6600
4	27.5×10^6	21·5	6000
4(a)	26.6×10^6	21	5750
5	32.0×10^6	21	4800
6	27.8×10^6	20	7800

* Steel No. 1 was obtained from a different source from the other materials tested, and its previous history is uncertain.

The most serious error in these determinations is that due to the uncertainty in the value of the moment of inertia of the cross-section of the test-piece (I) due to errors in machining. Since :

$$I = \frac{bd^3}{12}$$

$$\frac{\delta I}{I} = \frac{\delta b}{b} + \frac{3}{d}\delta d,$$

δI being the error in I due to an error δb in the width and δd in the thickness of the test-piece.[11] To obtain the same accuracy in the determinations of the absolute value of the modulus of elasticity as in the comparative determinations would necessitate an accuracy of 10^{-5} in. in the dimensions b and d. The accuracy in practice was of the order of 10^{-4} in., giving a maximum possible error of up to $\frac{1}{2}\%$.

Acknowledgment.

The authors wish to express their thanks to Dr. J. W. Cuthbertson for his interest and advice in connection with the modification made to his original apparatus, to the Alloy Steels Research Committee for a grant which enabled the work to be carried out, and to Dr. W. H. Hatfield, F.R.S., for the range of steels examined.

REFERENCES.

(1) Cuthbertson *Journal of Scientific Instruments*, 1937, vol. 14, No. 8, p. 268.
(2) Cuthbertson : *Journal of the Institute of Metals*, 1939, vol. 64, p. 209.
(3) Searle : "Experimental Elasticity." Cambridge, 1908 : Cambridge University Press.
(4) Timoshenko : *Mechanical Engineering*, 1923, vol. 45, p. 259.
(5) Chevenard : *Comptes Rendus*, 1918, vol. 166, p. 73.
(6) Lea : *Engineering*, 1922, vol. 113, p. 829.
(7) Goffey and Thompson : *Journal of The Iron and Steel Institute*, 1923, No. I., p. 465.
(8) Marshall and Thompson : Second Report of the Alloy Steels Research Committee, Section VI. (1), p. 147, *Iron and Steel Institute*, 1939, *Special Report No.* 24.
(9) Fahlenbrach and Meyer : *Technische Mitteilungen Krupp, Technische Berichte*, 1940, vol. 8, Apr., p. 25.
(10) Jaquerod and Mügeli : *Helvetia Physica Acta*, 1931, vol. 4, p. 3.
(11) Richardson : *Mechanical Engineering*, 1923, vol. 45, p. 259.
(12) Sykes and Evans : *Journal of The Iron and Steel Institute*, 1938, No. II., p. 125 P. (This paper contains an excellent bibliography.)

THERMO-ELECTRIC POWER OF VERY PURE IRON BETWEEN 20° AND 230° C.*

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(University of Manchester).

Paper No. 8/1943 *of the Alloy Steels Research Committee.*

Summary.

The thermo-electric power of very pure iron has been accurately measured in the temperature range from 20° C. to 230° C. No abnormalities which clearly exceed the experimental error have been noticed. The effects of such factors as the presence of hydrogen and cold-work have also been investigated, without any discrepancies being observed. The results tend to endorse the view, put forward by Sykes and Jones, that the abnormalities in the mechanical properties of iron and its alloys are not reproduced in its more definitely physical properties.

In their paper on discontinuities in the resistance-temperature curve of iron, Sykes and Jones (1) say that if it can be shown that "structure-insensitive" properties such as specific heat and electrical resistance vary continuously with temperature, then the reasons for the anomalous changes in mechanical properties must be sought from a consideration of such properties as grain boundaries, grain size, precipitation effects, &c.

Their results, as well as those of Sykes and Evans (2) on the specific-heat curve, support the view that, while irregularities do admittedly occur in the mechanical properties as the temperature is raised, properties of a purely physical nature do not.

Such a physical property, which may be measured with a high degree of accuracy, is the thermo-electric power. For the purpose of examining the variation of this property with temperature, Dr. W. J. P. Rohn provided the authors with two samples of iron wire, 0·2 mm. in dia., of the highest possible purity. One of these was a vacuum-melted electrolytic iron, the second a very pure, vacuum-melted carbonyl iron, both samples being vacuum-annealed after drawing. Their analyses are recorded in Table I.

The thermo-electric power of iron has already been investigated by more than one worker, but the differences in the results obtained and the great purity of the material now available appeared to justify further examination.

In a paper on the thermo-electric power of iron at temperatures up to 1000° C., Burgess and Scott (3) reported a smooth curve in the

* Received August 22, 1942. This paper is published by authority of the Alloy Steels Research Committee. The views expressed in it are the authors', and are not necessarily endorsed by the Committee as a body.

Table I.—*Analyses of Materials.*

Material.	C. %.	Si. %.	Mn. %.	S. %.	P. %.	Cu. %.	Ni. %.	Total Impurities. %.
Vacuum-melted electrolytic iron	0·02	Trace	0·06	0·025	Trace	0·03	...	0·135
Vacuum-melted carbonyl iron	0·01	0·005	0·05	0·001	0·003	0·004	0·05	0·123

lower temperature range. They admitted, however, that their method did not lend itself well to very accurate results at temperatures below about 400° C., on account of the effect of draughts and the consequent difficulty of maintaining uniformity in the increase of temperature.

On the other hand, Borelius and Gunneson,[4] in their investigation of the thermo-electric power of iron, found abnormalities at several temperatures. In these experiments the specimen was heated to the desired temperature in a specially constructed electric furnace and quickly quenched in cold water. In certain cases, they heated the same specimen to various temperatures, while in others they used the same specimen once only. These wires were made into couples with the untreated wire of the same material, and the thermo-electric powers were measured by comparison with a couple of known thermal e.m.f. Periodic irregularities were obtained when these results were plotted against temperature. Repeat experiments with same material showed that, though the curve was slightly displaced, the abnormalities occurred at approximately the same temperatures, suggesting that these were due to some kind of transformation of a hitherto unknown character.

Borelius[5] continued these experiments with hydrogen-bearing electrolytic iron, vacuum-melted electrolytic iron, both untreated and heated in coal-gas, and a high-silicon iron. He found evidence of transformation in all these materials, abnormalities which persisted even in the vacuum-melted electrolytic iron, the purest form of iron then available. This was held to show that these transformations were not due to the presence of gases, but were an inherent characteristic of iron itself.

Thompson and Whitehead[6] also noticed abnormalities in the thermo-electric power of 0·15% and 1·0% carbon steels against platinum, the hot junction being immersed in a gas-heated oil-bath which was thoroughly stirred. They heated the specimen to gradually ascending temperatures and used the deflection of a high-resistance mirror galvanometer as a measure of the thermo-electric power.

Experimental.

In brief, the experimental arrangement adopted in this work consisted in using a triple junction of iron, silver and constantan,

of which the iron–silver wires were used to measure the e.m.f. and the silver–constantan couple to determine the temperature at the exact point of the iron–silver junction.

The wires were most carefully twisted together to avoid any contamination of the iron resulting from soldering, and insulated from each other by inserting them in thin-walled glass tubes. To minimise loss of heat due to conduction along the wires, a length of about 6 in. was immersed in the oil-bath. This was heated by two resistors on opposite sides, and thoroughly stirred by the two stirrers shown in Fig. 1. A rheostat placed in series with the heaters controlled the rate of increase of temperature. The other ends of the wires were connected to the potentiometer leads in a thermos flask

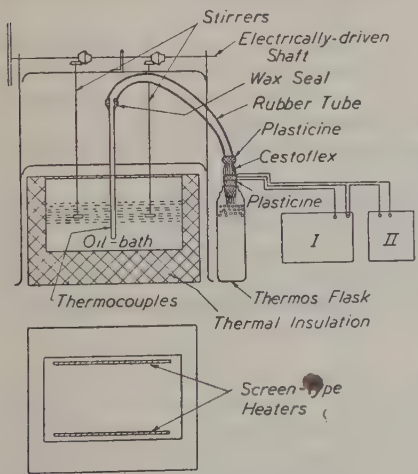

FIG. 1.—Apparatus for Determining Thermo-Electric Power.

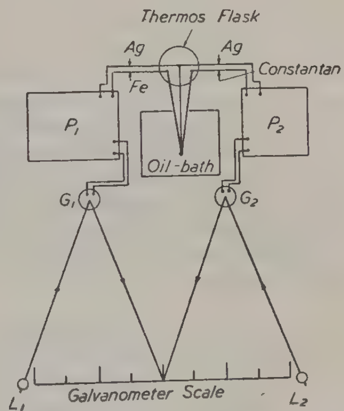

FIG. 2.—Circuit Diagram for the Measurement of Thermo-Electric Power.

filled with ice and water. In order to avoid corrosion, the wires between the ends of the glass tubes and the flask were threaded through thin rubber tubing, the junctions of the glass and rubber being sealed.

The iron and constantan wires were taken to potentiometers I. and II., respectively, the silver wire being connected to both. Potentiometer I., used for the measurement of the thermo-electric power of the silver–iron couple, was a precision instrument manufactured by Tinsley. Two sensitive galvanometers and lamps were employed for the potentiometric measurements, both spots of light being received on the same scale, Fig. 2.

Before any readings were taken, the batteries for the potentiometers were fully charged and then allowed to discharge through the

potentiometer circuit for about 3 hr. The discharge voltage was then found to remain steady for three or four series of readings. Nevertheless, in order to eliminate small unknown errors due to slight unbalance of the potentiometer circuits, both the potentiometer rheostats were rebalanced against the standard cell before every single reading.

When taking a curve, the following procedure was adopted: The heating current was switched on and the rheostat adjusted to give the required rate of increase of temperature. The contact stud of the potentiometer used to measure the temperature (P_2) was moved through 70 microvolts (approximately 2° C.), and when the spot of light from the galvanometer G_2 actually passed through the null point, the readings of the potentiometer P_1 as well as the deflection of the galvanometer G_1 were carefully noted.

This procedure enabled the reading of the thermo-electric power of the iron to be taken at the precise moment of passage through the null point of the spot of light from the temperature couple, exact temperature measurements being assured.

The contact of P_2 was again moved through another 70 microvolts and the process repeated.

It is difficult to estimate the exact experimental error of the present arrangement, as the major part of this error was bound up with the shortcomings in the instruments, but the individual observations are believed to be accurate to about $\pm$ 0·1 microvolts.

In the case of the electrolytic iron the following curves, Fig. 3, were obtained:

> *A1.*—After a preliminary heating to 230° C. in 6 hr., at which temperature it was held for 45 min., the specimen was allowed to cool freely. (This curve was rejected as being unsatisfactory.) The wire was then reheated to 230° C. in 6 hr., held there for ½ hr., and readings were taken down to 154° C. as it cooled freely. About 16 hr. later it was reheated to 166° C. in 2 hr., held there for 1 hr., and cooled freely.
>
> *A2.*—Heated to 140° C. in 4½ hr., held there for 1 hr. and cooled freely.
>
> *A3.*—Careful repetition of *A2.*
>
> *A4.*—Heated to 140° C. in 7 hr., held there for 45 min., and allowed to cool freely.
>
> *A5.*—Heated to 230° C. in 7½ hr.
>
> *A6.*—Heated to 140° C. in 2 hr.

The only curve, *B*1, obtained with the carbonyl iron was taken during heating to 230° C. in 7½ hr.

Some lengths of the electrolytic iron wire were then heated to a high temperature, about 1300° C., in hydrogen and quickly cooled in the gas. For comparison, another length was similarly treated in high vacuum and cooled slowly. The curves obtained for these

materials are reproduced in Fig. 4, $H1$ referring to the hydrogen-treated sample, and $H2$ to the vacuum-annealed material. Curve $H3$ refers to the wire treated in hydrogen and then elongated 17% in tension.

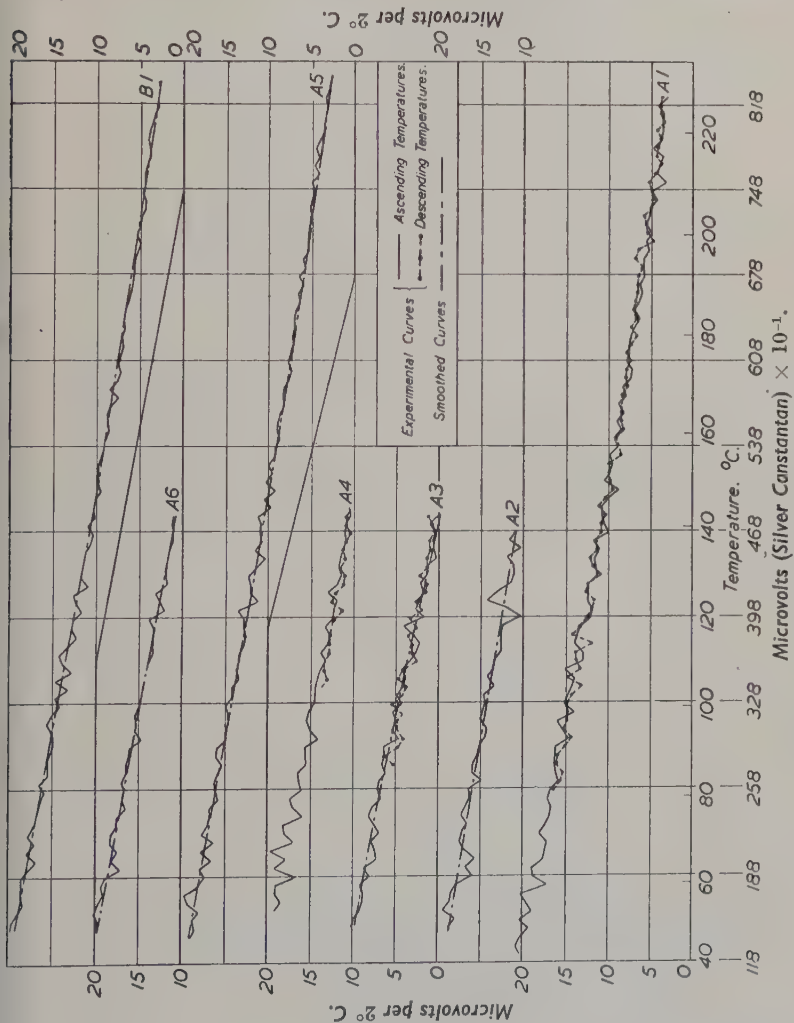

Fig. 3.—Thermo-Electric-Power/Temperature Curves.

Conclusions.

With the exception of curve $A2$, to which reference is made later, none of the curves shows any marked or consistent abnor-

mality. As has been said, it is not easy to assess the magnitude of the probable experimental error, but it is doubtful whether there are any irregularities which exceed it.

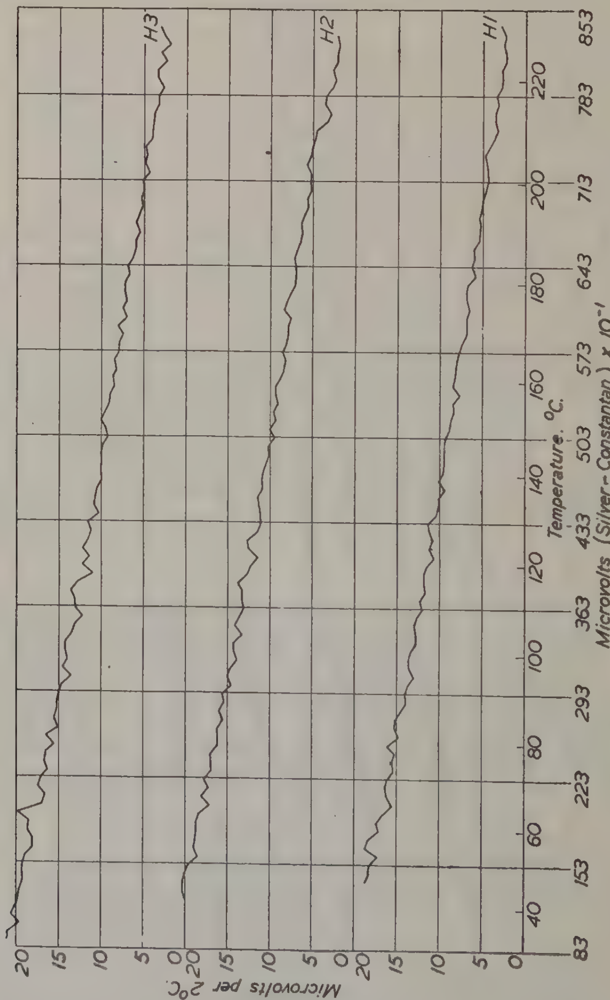

Fig. 4.—Thermo-Electric-Power/Temperature Curves.

The peak around 120° C. in $A2$ is due to an accident which necessitated the shutting off of the heating current for a short time, and is not shown in the repeat run $A3$.

It will be noted that as the temperature of the oil-bath rises the

curves become progressively smoother, a fact to be attributed to the more uniform temperature as the viscosity of the oil diminishes.

The curves for the wires heated in hydrogen show no appreciable alteration, either as treated or after cold-work, whence it would appear reasonable to suppose that this gas is not the cause of the abnormalities found in the mechanical properties of ordinary steels.

So far, then, as this work goes, it is not inconsistent with the views of Sykes and Jones that the oft-recorded abnormalities in the mechanical properties of iron and its alloys are not reproduced in curves of more purely physical properties of the " pure " metal.

The authors would acknowledge the great assistance that they have received from Dr. J. W. Cuthbertson, and one of them (N. C. S.) thanks the University of Glasgow for a J. R. K. Law Scholarship.

REFERENCES.

(1) Sykes and Jones : *Journal of The Iron and Steel Institute*, 1939, No. I., p. 435P.
(2) Sykes and Evans : *Journal of The Iron and Steel Institute*, 1938, No. II., p. 125P.
(3) Burgess and Scott : *Bulletin of the Bureau of Standards*, 1918, vol. 14, p. 15.
(4) Borelius and Gunneson : *Annalen der Physik*, 1922, vol. 67, p. 227.
(5) Borelius : *Annalen der Physik*, 1922, vol. 67, p. 236.
(6) Thompson and Whitehead : *Proceedings of the Royal Society*, 1923, A., vol. 102, p. 587.

CORRESPONDENCE.

Dr. C. SYKES, F.R.S. (The National Physical Laboratory, Teddington), wrote: The results of the investigation recorded in this paper are in agreement with the view that the structure-insensitive properties of iron, thermo-electric power, resistivity and specific heat, vary continuously with temperature in the range 20–230° C. and thus controvert the results of Borelius and Gunneson.[1]

I have always felt particularly sceptical about the anomalies in thermo-electric power which were referred to as resulting from the "intrinsic" properties of the metal iron on the purely practical grounds that the iron-constantan combination is used so successfully as a thermocouple. In view of this usage and the careful investigation that it has received at the hands of such organisations as the U.S. Bureau of Standards, it was difficult to understand how any substantial anomalies could have eluded discovery for so long.

Mr. W. C. HESELWOOD (Central Research Department, The United Steel Companies, Ltd., Stocksbridge, near Sheffield) wrote: This paper has achieved its main purpose by providing confirmation (within its limits of accuracy) that the thermo-electric-power/temperature curve for iron does not show abnormalities corresponding with abnormalities sometimes reported in certain other properties. It is desired to comment only on the accuracy of the results and the purity of the iron used.

(1) *Accuracy.*—This seems to be a little indefinite; the summary claims that the thermo-electric power "has been accurately measured," whereas the conclusions contain the phrase "it is not easy to assess the magnitude of the probable experimental error."

It is difficult to associate irregularities (as is suggested in the paper) with temperature variation in the oil-bath. The three wires of the double thermocouple are twisted into a common junction; surely the actual temperature of *this* junction is the controlling temperature, and temperature variation in the oil or even along the wires can have little effect.

(2) *Purity.*—The iron used is described as "of the highest possible purity," but it is interesting to note that Cleaves and Hiegel[2] recently determined many mechanical and physical properties of iron containing only 0·01% of total impurities compared with 0·13% in the wire used by the present authors. The American work does not, however, include results that can be compared with those in the present paper.

[1] *Annalen der Physik*, 1922, vol. 67, p. 236.

[2] *Journal of Research of the National Bureau of Standards*, 1942, vol. 28, May, p. 643.

AUTHORS' REPLY.

In reply to the written discussion, the Authors need make two observations only. In the first place both of the quotations from the paper given by Mr. Heselwood may be reconciled if he will put "small" in front of "experimental error." With regard to the question of purity, the material was "of the highest possible purity" at the time the work was carried out, whilst, in addition, it is not unreasonable at the moment to view the possibility of producing iron with 0·01% of total impurities with some scepticism.

THE EFFECT OF ZINC ON THE CORROSION-FATIGUE LIFE OF STEEL.[1]

By N. STUART, Ph.D., D.I.C., and U. R. EVANS, Sc.D.
(Cambridge University).

Paper No. 8/1943 *of the Corrosion Committee.*

(Figs. 1 and 2 = Plate I.)

Summary.

Earlier work at Cambridge and elsewhere has shown that on steel wetted with nearly neutral chloride solutions contact with zinc prolongs the fatigue life. There appeared, however, a danger that in acid liquids contact with zinc might increase the hydrogen charge and thus enhance the fragility. Most of the demonstrations of brittleness caused by a hydrogen charge in steel refer to stresses which, in the absence of hydrogen, would be sufficient to cause plastic flow; it seemed important to ascertain whether, within the elastic range, contact with zinc improved or shortened the life of steels bent in the presence of acid of different concentrations; the effect of nickel contacts was also studied.

A machine was set up which permitted the alternating bending of twenty thin steel strips simultaneously in a thermostat room, so as to give mean values which would be reliable—despite the scatter of results invariably met with in work of this kind.

It was found that on cold-rolled steel (0·26% carbon) wetted with relatively strong acid a zinc contact increased the fatigue life of the steel. At 0·001N and 0·00125N contact with zinc had no significant influence, but here the life is relatively long in any case. Steel previously charged with hydrogen by cathodic treatment showed a long fatigue life, even though the gas charge far exceeded that which would be produced by contact with zinc. It is concluded that a hydrogen charge is not dangerous, if the alternating stressing does not exceed the range needed to produce permanent set. Specimens exposed to the atmosphere in contact with zinc suffered much less visible attack than those without zinc protectors, but the fatigue life was not increased.

It is concluded that contact with zinc may have value in some conditions, and that the dangers arising from a hydrogen charge are not serious.

Introduction.

The Problem.

Cathodic protection, whether obtained by contact with zinc or by the application of an external e.m.f., has frequently been suggested as a means of overcoming the corrosion-fatigue of steel,

[1] Received August 25, 1942. This paper is published by authority of the Corrosion Committee. The views expressed in it are the authors', and are not necessarily endorsed by the Committee as a body.

notably by Behrens.[1] Gould's investigations at Cambridge[2] on the corrosion-fatigue of wire in the Haigh-Robertson machine showed that loose winding with zinc ribbon, even though it did not prevent access of the corrosive agent to the metal, greatly increased the corrosion-fatigue life in the presence of chloride solutions. Later work at Cambridge by Deer and Sleigh on the hydrogen embrittlement produced by certain acid media suggested that hydrogen in steel diminishes, under certain circumstances, not only the impact strength but also the life when subjected to alternating bending. Now, contact with zinc in the presence of acid rain or condensate would be liable to increase the hydrogen charge in steel, and this suggested the fear that contact with zinc, although prolonging the life in neutral chloride solutions, might shorten it in the presence of acids. *This is clearly a point which must be tested before zinc contacts can be recommended for general use in overcoming corrosion-fatigue.* Any protective method which prolongs life under certain circumstances and shortens it under others (especially if the shortening occurs under just those conditions where the life would be short in any case) is open to grave objection. The stresses used in the work of Deer and Sleigh, however, may have exceeded the elastic range. Since, in general, service stresses will not introduce plastic deformation, it appeared important to conduct tests at stresses within the elastic range. As the shortening of life mentioned above had been obtained at low frequencies, the present work was also carried out at low frequencies, and a wide range of acidities was studied, extending to concentrations far higher than those which would occur in rain or natural waters.

The Programme.

The experiments designed to answer the question propounded above fell into three series :

Series 1.—Steel strips, *not previously corroded*, were subjected to *alternating bending in the presence of sulphuric acid of different concentrations*, with and without zinc contact pieces. Specimens with nickel contact pieces were also tested. The nickel should act electrochemically in the contrary direction to zinc. The charging of the iron with hydrogen should be stimulated by contact with a zinc anode, and reduced by contact with a nickel cathode; if, therefore, hydrogen causes embrittlement, zinc should be harmful, and nickel beneficial. On the other hand, corrosion proper will be diminished by contact with zinc, and stimulated by contact with

[1] O. Behrens, *Mitteilungen des Wöhler-Instituts* (*Braunschweig*), 1933, No. 15.

[2] A. J. Gould and U. R. Evans, *Iron and Steel Institute*, 1939, *Special Report* No. 24, p. 325. *Cf.* the good effect of zinc coats on the endurance of Duralumin found by I. J. Gerard and H. Sutton (*Journal of the Institute of Metals*, 1935, vol. 56, p. 44) and the statement of R. P. Haigh (*loc. cit.*, p. 47) that on steel wonderfully good results were obtained even if there were holes in the zinc coat.

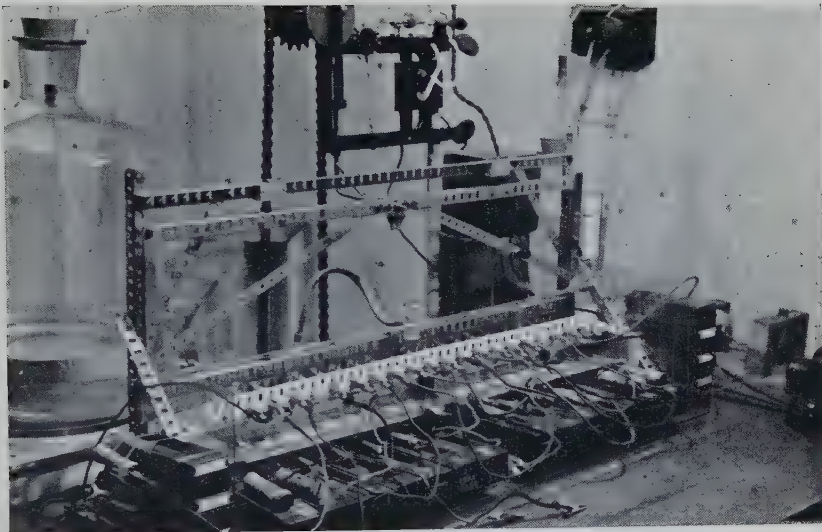

FIG. 1.—Front View of the Testing Machine, showing counters.

FIG. 2.—Side View, showing specimens and feeding arrangement.

[*Stuart & Evans.*

[*To face p.* 132 P.

nickel, and this factor should tend to make zinc prolong the life, and nickel shorten it.

Series 2.—Steel strips which had *previously received cathodic treatment* in acid containing arsenic, so as to be strongly charged with hydrogen, were subjected to alternating bending in the machine, *no acid being applied during the test.* The object was to ascertain whether, in cases where beyond all question hydrogen was present, the fatigue life would be reduced. Ploum and Bardenheuer [1] had found that such a treatment does produce embrittlement in bending tests, which evidently went well beyond the yield point.

Series 3.—Steel strips were *exposed to the atmosphere with or without zinc contact pieces*, and were afterwards tested in an alternating bending machine, to ascertain whether contact with zinc had diminished or increased the fatigue life. Neither of these changes would have been surprising. Contact with zinc might charge the steel with hydrogen and thus cause embrittlement; alternatively it might prevent pitting, owing to cathodic protection, and thus avoid the stress concentration which pits can sometimes produce.

The Experiments.

The Materials.

The analyses of the materials used are shown in Table I.

TABLE I.—*Analyses of Test Materials.*

	Steel *M*.	Steel *US*2.
Carbon	0·13%	0·26%
Manganese	0·35%	0·36%
Silicon	0·01%	0·207%
Sulphur	0·061%	0·031%
Phosphorus	0·060%	0·038%
Copper	0·08%	...
Thickness	0·29–0·32 mm.	{ 0·32 mm. annealed 0·29 mm. cold-rolled

In preliminary experiments, steel *M*, a mild pack-annealed steel, as used in the South Wales tinplate industry, was employed, the marginal portions of the sheets being rejected. The surface of this steel was unsatisfactory and variable, whilst the thickness showed a serious fluctuation, which was particularly unfortunate, seeing that the fibre stress of a bent specimen depends upon the square of the thickness. As a result, the numbers obtained were very variable.

For the main tests, Dr. T. Swinden, of The United Steel Com-

[1] H. Ploum and P. Bardenheuer, *Mitteilungen aus dem Kaiser-Wilhelm Institut für Eisenforschung*, 1934, vol. 16, p. 129. *Cf.*, however, W. Machu and O. Ungersböck, *Archiv für das Eisenhüttenwesen*, 1942, vol. 15, p. 301.

panies, Ltd., very kindly arranged for the preparation of the steel strip *US*2, which showed satisfactory uniformity. Two coils were provided, one in the cold-rolled condition and the other annealed. The cold-rolled material was used in the experiments described below. The steel was kept heavily greased in a vessel containing quicklime and calcium chloride. Periodically a few yards were removed and cut up into specimens on a treadle guillotine; they were degreased with carbon tetrachloride and acetone, dried quickly with blotting paper and stored over calcium chloride. Tests were carried out with the as-rolled surface.

The Testing Machine.

The apparatus was set up in a thermostat room at 21° C. The machine, which is illustrated in Figs. 1 and 2, and (diagrammatically) in Fig. 3, was constructed of steel, with local use of

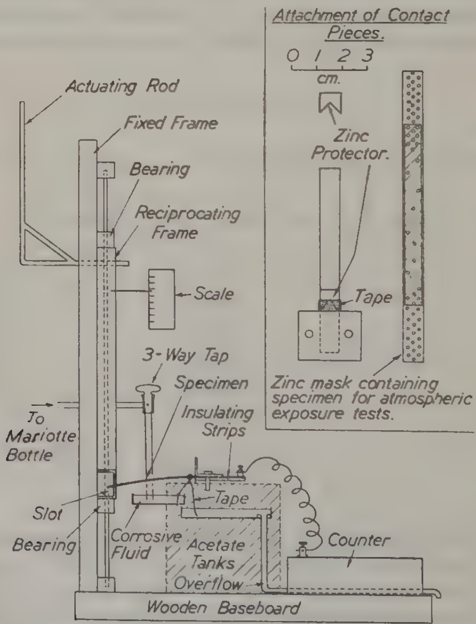

FIG. 3.—The Apparatus for Alternate Bending of Strips.

Meccano parts, strengthened where necessary to give rigidity. The machine was designed to test about twenty specimens, 7·3 × 0·8 cm., arranged horizontally like the keys of a pianoforte. At their stationary ends the specimens were gripped between Astralon (vinyl resin) insulators clamped together by steel pieces 56 cm. long; the clamped portions of the specimens extended about 1·6

cm. from their ends. About 0·65 cm. from their other ends, the specimens passed through a slit formed by two parallel bars which were part of a frame designed to slide up and down in a vertical plane. The reciprocating motion of this frame bent the specimens first up and then down, so that the external fibres of the steel near to the clamped end were subjected to alternating stresses, which reached a maximum at the " cantilever roots " where the specimens were clamped.

The reciprocating motion was provided by a 110-V. D.C. motor developing $\frac{1}{4}$ h.p., which operated a worm-reduction gear on to a toothed wheel carrying a bicycle chain. The speed was controlled by means of a rheostat shunted across the rotor windings.

In order to record automatically the moment of breaking, each specimen was connected to an electric circuit through a Post Office " operation counter " of a pattern formerly used for recording telephone calls. A wheel geared to the rotating drive of the machine tipped up an enclosed mercury trip-switch once every 10 cycles, and an electric current was thus sent through the specimens and actuated the counters. So soon as a given specimen broke, the circuit leading to the corresponding counter was interrupted, and the counter ceased to move on. Thus, to obtain the approximate fatigue life of a given specimen, it was only necessary to multiply the number recorded on the counter by 10.

To measure the stresses imparted to the specimens, experiments were carried out with similar specimens clamped at one end and bent by means of weights applied at the appropriate point near the other end. In this way the load needed to give the same deflection as was produced in the machine (indicated by a pointer moving over the scale) was ascertained, and the maximum stress at the external fibres near the root was obtained by the expression $6Wl/bh^2$, where l is the cantilever length (5·05 cm.), h the thickness (0·029 cm.), b the breadth (0·79 cm.) and W the weight applied. A simple proof of this expression is given in Appendix I.

At the *amplitude* ($\pm$ 1·1 cm.) used throughout the research, the stress in the external fibre of the cold-rolled steel locally reached 25 tons per sq. in. It was found that a bending load sufficient to cause this stress left no permanent set when repeatedly applied and removed, although when the load was sufficient to give 33·5 tons per sq. in. in the external fibre a permanent set appeared which increased on each renewed application; the relation between the deflection and load, shown in Fig. 4, indicates that 25 tons per sq. in. is still within the limit of proportionality.[1] Specimens subjected to the test without any corrosion before or during the bending invariably survived periods of 500,000 cycles, whereas

[1] The value of the stress at the external fibre needed to produce permanent set on a bent specimen will not necessarily agree with the stress at which it appears on a specimen stressed in tension uniformly throughout its cross-section.

specimens subjected to corrosion before or during the experiments usually had much shorter lives. On the other hand, tests on annealed specimens in the absence of corrosive agent generally fractured at about 100,000 cycles or less, the air fatigue limit being well exceeded in this case.

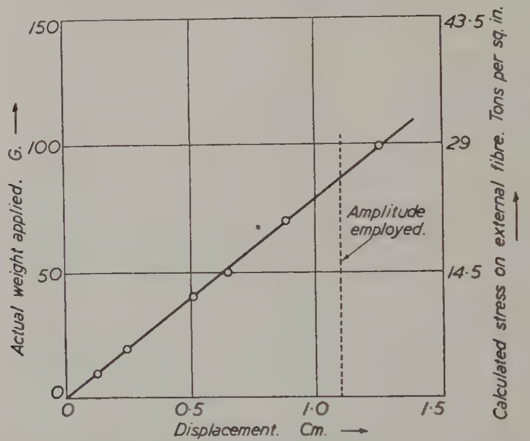

FIG. 4.—Relation between Stress and Strain for a Single Strip.

The *frequency* used throughout the work was a slow one, namely, 33 cycles per min. Thus, the length of a single cycle was 1·8 sec. The low frequency of stressing has resulted in values for the corrosion-fatigue life which, when expressed in numbers of cycles, may appear very low; if expressed as times, the values become more comparable with those commonly met with in corrosion-fatigue researches.

The weak point of the machine is that, when some of the specimens have broken, the amplitude of the bending applied to the remaining specimens tends to increase appreciably. This will not affect the order of merit of the specimens under comparison (*e.g.*, specimens with or without zinc contacts), although it will tend to diminish the contrast between the lives as compared with figures obtained on a perfect machine. For the purpose of the present test, this is of no great moment.

Series 1.

During these experiments the specimens were kept wet with acid by means of a wick tied round the specimens at the root. The wicks consisted of linen tape 0·4 cm. broad, previously boiled out with water. The upper end of the wick dipped into a rectangular reservoir containing the acid, which siphoned down to the specimen and then through the far end of the wick into another reservoir. The difference of level between the two reservoirs was 1·75 cm., and the acid in the upper reservoir was replenished at the required

TABLE II.—*Corrosion-Fatigue Lives of Cold-Rolled Specimens Wetted with Sulphuric Acid. Steel* US2.

The lives are expressed in units of a thousand cycles.

Acid Concentration (Normality).	Plain Metal.		In Contact with Zinc.		In Contact with Nickel.		Probability that Apparent Effect of Contact with Zinc is due to Chance.
	Individual Values.	Average.	Individual Values.	Average.	Individual Values.	Average.	
$0{\cdot}0006N$	88 109 95 116	102	140 168 134 116 175	147	71 90 107 100 99	93	Less than 0·01 (effect highly significant)
$0{\cdot}001N$	80 127 104 91 135	107	101 77 87 89 103	91	77 128 76 79 128	98	0·2 (effect not significant)
$0{\cdot}00125N$	91 116 117 91 86 102	100	78 94 93 131	99	76 117 100 124	104	Large (effect not significant)
$0{\cdot}002N$	37 50 71 38 41	47	100 80 166 188 208	148	77 52 63 62 44	60	Less than 0·01 (effect highly significant)
$0{\cdot}0025N$	No test made	Not found	114 73 99 93 131	99	95 73 75	81	...
$0{\cdot}01N$	47 46 66 51 80 43 49 59	57	65 70 103	79	66 71 81 43 65 59 47 67	61	0·03 (effect significant)
$0{\cdot}1N$	27 29 31 35	31	72 45 62 52 116	77	37 32 21 37 35	32	Less than 0·01 (effect highly significant)
$0{\cdot}25N$	19 15 19	18	44 37 103	61	24 24 15	21	Less than 0·01 (effect highly significant)

level by means of a Mariotte bottle. In some runs, two separate reservoirs and two Mariotte bottles containing acids of different concentrations were employed. The zinc or nickel contact pieces were pushed in between the wick and the steel strip in the manner shown in the inset of Fig. 3, which also defines the shape and size of these contact pieces.

This method of feeding appears quite satisfactory for acid liquids, but it is not suited for some neutral liquids, as the linen tape tends to become blocked with rust, so that feeding ceases.

The lives obtained with different concentrations of acid with and without contact pieces are shown in Table II. It will be observed that zinc appreciably lengthened the life at high concentrations, where a shortening of the life had been anticipated; at $0{\cdot}25N$, for instance, zinc increased the life 3·4 times. At lower concentrations the state of affairs was different. Indeed, at $0{\cdot}001N$ zinc seemed to produce a slight shortening of the mean life by about 14% of the original value, but application of the "*t*-test," explained in Appendix II., shows that the difference is not "significant." At high acid concentrations, contact with nickel gave slightly higher figures for the mean lives than were obtained in its absence, but the *t*-test showed the difference to be barely significant. One real alteration was, however, produced by nickel contact pieces; the fracture usually occurred, not at the cantilever root, where the stress was highest, but at the far edge of the nickel contact piece, where the stress is distinctly lower. This is probably due to the fact that the action of the cell Nickel | Acid | Steel will be stimulated by a supply of oxygen to the junction of steel and nickel, and for geometrical

TABLE III.—*Corrosion-Fatigue Lives of Specimens Wetted with Distilled Water and Rain Water. Steel* US2.

The lives are expressed in units of a thousand cycles.

Liquid Used.	Plain Metal.		In Contact with Zinc.		In Contact with Nickel.		Probability that Apparent Effect of Contact with Zinc is due to Chance.
	Individual Lives.	Average.	Individual Lives.	Average.	Individual Lives.	Average.	
Distilled water	146 88 139 124 133	126	106 93 105 88	98	105 97 79 88	92	0·05 (effect just significant)
Rain water (Cambridge)	98 118 97 91 148 171	120	193 223 200 177 230 148	195	85 90 99 97 140 156	111	Less than 0·01 (effect highly significant)

reasons this will be greater at the point in question than where the steel is clamped. The fact that nickel frequently permits fracture to occur at an area subjected to lower stresses than those needed to produce it in the absence of nickel in the time in question, suggests that—despite the figures obtained—contact with nickel might be dangerous in some situations.

Some results with distilled water and rain water are given in Table III. In distilled water, zinc certainly confers no benefit; indeed, there is a slight worsening, which the *t*-test shows to be just significant. In rain water—possibly owing to its higher conductivity—there is a marked increase of life, which the *t*-test shows to be significant.

Series 2.

The fact that contact with zinc did not produce shortening of the life in high acid concentrations in the experiments of Series 1 might be explained in two ways:

(1) It may be that the hydrogen charge produced by contact with zinc is too small to cause embrittlement.

(2) It may be that any hydrogen charge, however large, would not be dangerous, provided that the stress never reached the values which produce plastic deformation in hydrogen-free steel.

In order to distinguish between these two explanations, it seemed advisable to carry out experiments with specimens which *beyond all question contained hydrogen.*

An electrolytic cell was set up in which seven specimens clamped to a nickel-plated holder were subjected for periods of up to 3 hr. to cathodic treatment in $0{\cdot}1N$ sulphuric acid containing 3 mg. of arsenic per litre at a current density of 21 m.amp. per sq. cm. The arsenic serves to prevent the escape of hydrogen from the steel.[1] The specimens, after such a process, were strongly charged with hydrogen, and produced rapid effervescence when introduced into hot water, one volume of steel evolving three volumes of hydrogen. If tested by bending between the fingers just after being charged with hydrogen, they were found to be very brittle, but when tested on the machine they remained unbroken over a 500,000-cycle period.

It would seem that a charge of hydrogen vastly in excess of anything which would be likely to be produced through a zinc contact piece leads to no serious drop in the fatigue life, provided that the alternating stresses take place within the elastic range. Probably the premature breakage of steel charged with hydrogen in more severe mechanical tests is due to the fact that hydrogen

[1] *Cf.* A. H. W. Aten, *Recueils des Travaux Chimiques des Pays Bas*, 1930, vol. 49, p. 641; 1931, vol. 50, p. 943. W. Baukloh and G. Zimmermann, *Archiv für das Eisenhüttenwesen*, 1936, vol. 9, p. 459.

interferes with plastic flow so that fracture occurs in its place.[1] If the stressing is confined to the elastic range, no shortening of the life need be anticipated, and, in point of fact, none is produced.

Series 3.

It is well known that specimens exposed to atmospheric corrosion suffer in fatigue properties, owing to the stress concentration at pits, or possibly to loss of thickness. It seemed reasonable to expect that contact with zinc might prevent this loss of corrosion-fatigue life, although it was also conceivable that the life might be shortened, owing to an increase in the charge of hydrogen.

Specimens were exposed on the roof of the Chemical Laboratory, Cambridge, on the frame described elsewhere.[2] Some of these specimens were provided with masks of perforated zinc, of the form shown in the inset of Fig. 3, some with masks of perforated Astralon (vinyl resin), and some were without any masks. After a period of rainy weather, they were brought in and tested in the machine. The lives are shown in Table IV. It will be observed

TABLE IV.—*Fatigue Lives after* 6 *Days on Roof in Rainy Weather. Steel* US2.

The lives are expressed in units of a thousand cycles.

With Zinc Masks.		Plain Metal.		With Astralon Masks.	
Individual Lives.	Average.	Individual Lives.	Average.	Individual Lives.	Average.
113		77		117	
118	124	107	128	134	137
132		152		142	
133		176		156	

that contact with zinc, although greatly reducing the visible corrosion, has not prolonged the fatigue life; if anything, it has diminished it. The shortening of the life is not sufficient to be of practical importance, and the *t*-test (*see* Appendix II.) shows that it is not "significant."

PRACTICAL CONCLUSIONS.

The Effect of Zinc Protectors on Fatigue Life.

The fear that a hydrogen charge resulting from contact with zinc in a strongly acid environment might shorten the fatigue life of steel has proved unfounded—at least for stressing within the elastic range under the conditions covered by the experiments.

[1] Reasons for this change are suggested by U. R. Evans in *Journal of The Iron and Steel Institute*, 1942, No. II., p. 257 P.

[2] S. C. Britton and U. R. Evans, *Journal of the Society of Chemical Industry*, 1930, vol. 49, p. 173 T.

A hydrogen charge far greater than that which contact with zinc could yield has failed to reduce the life to the low values invariably obtained when acid is present during the application of alternating stress. Although a long series of experiments would be needed to prove that the danger is in all circumstances non-existent, there seems no urgent necessity to explore the situation further at present, since the conditions studied were those which—in the light of previous work—would seem most likely to prove disastrous.

The fear which prompted the research was that, if zinc protectors were fitted to deal with a nearly neutral conducting liquid (*e.g.*, sea water), and if, through some unforeseen circumstance, the environment became acid, the life would become even shorter than if no zinc protectors had been fitted; if this fear had been confirmed, great hesitation would have been felt in recommending zinc to combat corrosion-fatigue.

Theoretical interest attaches to the fact that at greater dilutions the benefit of zinc contact pieces declines, disappearing altogether at $0{\cdot}00125N$ and $0{\cdot}001N$, but reappearing in $0{\cdot}0006N$ acid and also in rain water. The situation is certainly complicated, but arguments similar to those used in explaining concentric rust rings [1] would seem to suggest that, as the concentration is diminished, the effect of a zinc contact piece at any given distance should alternately decline and recover. But the matter has little practical importance, and the question whether the apparent adverse effect of zinc in $0{\cdot}001N$ acid is real or not, hardly affects the decision as to whether zinc can be recommended as a protective agent, because the conditions under consideration are such that the corrosion-fatigue life is in any case long. There is no serious objection to a protective method which slightly enhances damage when the conditions are such that damage is in any case slow, provided that it restrains damage when it would otherwise be rapid; it is the agency which accelerates damage just when it would *in any case* be rapid, and restrains it only when it would in any case be slow, that must be regarded with suspicion.

The conclusion is that *there need be no undue hesitation in developing methods of combating corrosion-fatigue based on the use of zinc.*

Modes of Application of Zinc Protectors.

The manner in which zinc can be brought into contact with steel will depend on the shape and environment of the part liable to corrosion-fatigue. Hot-galvanising or electrodeposited coats protect partly mechanically and partly electrochemically, but they cannot be applied or renewed "in the field." There are several paints rich in zinc dust now in course of development by Dr. J. E. O. Mayne and one of the authors in the Cambridge University Corrosion

[1] U. R. Evans, "Metallic Corrosion, Passivity and Protection," p. 349. London, 1937: Edward Arnold & Co.

Laboratory, which give electrochemical protection against corrosion at gaps in the coat; experiments to test whether they will protect also against corrosion-fatigue are now being carried out by Mr. A. U. Huddle. Another possibility is a winding of zinc ribbon (which can be attached, if desired, by an organic adhesive), as in Dr. Gould's work. Of course, in cases where the clearance is small, and notably in bearing surfaces, such methods are impossible, but it may then be considered whether zinc dust could not be introduced into the lubricant.

With proper consideration of the electrochemical principles involved, there seems hope that the use of zinc may serve to prolong corrosion-fatigue life under suitable conditions. It is of little or no value for poorly conducting liquids, but such liquids are not usually dangerous.

The authors would like to acknowledge the help derived from discussions with Dr. A. J. Gould, Dr. T. P. Hoar, Dr. J. N. Agar and Mr. A. U. Huddle, and to thank Dr. R. S. Thornhill, who very kindly executed the diagrams. They would also acknowledge the support and interest of the Alloys Steel Research Committee and the Corrosion Committee of The Iron and Steel Institute, and particularly that of the Chairman, Dr. W. H. Hatfield, F.R.S., and Vice-Chairman, Dr. T. Swinden, who also arranged for the provision of the steel employed. Finally they would recognise the courtesy of the London County Council Education Authority, who have released one of them (N. S.) for this research.

Appendix I.—*Maximal Fibre Stress at Cantilever Root.*

Suppose a weight W is suspended at distance l from the cantilever root (the place where the specimen is clamped), the breadth of the cantilever being b and thickness h, and suppose that S_M be the maximal stress which exists at the external fibres (tensional on one face and compressional at the other).

The place where the stress attains the value S_M is at a distance $h/2$ from the neutral axis; at any other distance (y) from the neutral axis it will clearly be:

$$\frac{y}{h/2} S_M.$$

Thus, the moment which resists bending on the tensional side will be:

$$\int_0^{h/2} \frac{yS_M}{h/2} \cdot ybdy = \frac{2S_M b}{h} \int_0^{h/2} y^2 dy = \frac{2S_M b}{h} \cdot \frac{1}{3} \cdot \frac{h^3}{8} = \frac{S_M bh^2}{12}.$$

Since the resisting moment on the compressional side is the same, the total resisting moment will be $S_M bh^2/6$, and this must balance the bending moment Wl. Thus:

$$Wl = S_M bh^2/6$$

or

$$S_M = 6Wl/bh^2.$$

APPENDIX II.—*Use of the "t-Test" for Significance.*

If a series of experimental results shows scatter and if the series is repeated *under identical conditions*, the mean of the second series will in general be different from that of the first. If, however, the second series differs from the first in one respect, namely, that zinc contact pieces are fitted in the second case but not in the first, and if a difference is recorded between the two means, the question will at once be asked: Is this difference attributable to the zinc protectors, or is it merely due to the play of chance? Clearly if the difference *between* the means of the two series is large compared to the scatter *within* each series, then common sense indicates that zinc has had a significant effect; if it is small compared to the latter, it provides no evidence that zinc has had any influence at all. In doubtful cases, statistical mathematics must be employed to calculate the probability as to whether the difference reached is due to a *real* difference between the two series, or whether the two series are really "identical" (the zinc having had no influence). Clearly the number of experiments must be taken into account, since the greater this number is, the more closely will the experimental mean approach the true mean—which would be obtained by averaging the results of an infinite number of experiments. The *t*-function is a useful statistic introducing the difference between the mean values of the two series ($\bar{X}_1$ and $\bar{X}_2$), expressed as a fraction of the standard deviation, which is a suitable measure of the scatter within the series, and also introducing the number of experiments performed. It is defined as follows:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S} \sqrt{\frac{n_1 n_2}{n_1 + n_2}}$$

where n_1 and n_2 are the number of experiments in each series, and S, the estimated standard deviation, is obtained from the expression:

$$S = \sqrt{\frac{\Sigma D_1^2 + \Sigma D_2^2}{(n_1 - 1) + (n_2 - 1)}},$$

D_1 and D_2 representing the deviations of the individual measurements in the two series from the respective means. The reason for the appearance of $(n_1 - 1)$ and $(n_2 - 1)$ instead of n_1 and n_2 in the denominator is that, in each series, the degrees of freedom will be one less than the number of experiments, since the deviations are measured from an experimentally determined mean; as soon as $(n - 1)$ values of the deviation have been written down, the last value is *already fixed*, since one value (and one only) will keep the mean at the value adopted throughout.

By calculating t and consulting tables available for the purpose,[1] it is possible to write down at once the probability that the difference

[1] *See*, for instance, R. A. Fisher, "Statistical Methods for Research Workers." London, 1941: Oliver and Boyd.

between the means of the two series is merely a freak of chance, and not attributable to the zinc protectors.

The method has been used in cases where the difference between the results obtained in presence and absence of zinc is small. For instance, the difference given in Table IV. for the two sets of four *US*2 steel specimens exposed to the atmosphere with and without zinc contact pieces leads to $t = 1{\cdot}36$, which indicates a probability of 0·2 that the difference is fortuitous. Such a difference cannot, therefore, be regarded as conclusive proof that the zinc contact pieces have produced a real worsening of the life. Similarly, two sets of *M* steel specimens (26 with zinc, 13 without zinc) exposed on the roof show a difference between the mean values, but application of the *t*-test indicates that there is a 0·3 chance that this is only fortuitous. Here again there is no convincing evidence that the influence of zinc is significant. Again, with reference to Table II., giving the lives of *US*2 steel specimens tested with and without zinc protectors in 0·001*N* acid, the slight apparent worsening due to zinc is not significant, since the *t*-test gives a value of 1·36, corresponding to a probability of 0·2 that the difference is due to chance. On the other hand, the contrast between zinc and nickel contact pieces in 0·0006*N* acid leads to $t = 4{\cdot}2$, and here the probability is less than 0·01 that the difference is fortuitous; the effect of the nature of the contact material must here be regarded as "significant."

THE YIELD POINT IN STEEL.*

By C. A. EDWARDS, D.Sc., F.R.S., D. L. PHILLIPS, M.Sc., and Y. H. LIU, B.Met., M.Sc. (University College, Swansea).

Summary.

Some of the explanations which have been offered to account for the phenomena of the "upper" and "lower" yield points in mild steel during tensile testing have been examined. It is confirmed that the behaviour of mild steel in this respect is an intrinsic property of the material, and is not due to the inertia of the testing equipment. It is also confirmed that the value of the yield stress is affected by the rate of loading. No support has been obtained for the hypothesis that the yield point is due to some kind of retardation in the ability of the metal to react to increasing stresses, if insufficient time is given for plastic deformation to be initiated, and that no yield point would be shown in mild steel if extremely slow rates of loading were used. The yield point in mild steel can no longer be attributed to the body-centred cubic lattice structure, since similar kinds of yield points have been found with alloys in which the solvent metals possess the face-centred structure. The authors believe that when a yield point is obtained, it is associated with the presence in the metal of an element which is more soluble at high than at low temperatures, and with a treatment which causes this element to be precipitated on certain planes of slip within the crystals.

Introduction.

The study of the behaviour of metals during their plastic deformation has formed the subject of many investigations which have been undertaken with a variety of purposes in mind. These have led to the accumulation of a considerable amount of interesting and useful evidence which has increased our knowledge of what happens during the straining of metallic crystals and crystalline aggregates. There are, however, many aspects of the subject which are not completely understood. This is especially evident when the behaviour of a typical non-ferrous metal or alloy is compared with that of ordinary mild steel during the early stages of tensile testing. With the former, the stress-strain diagram indicates that, after a certain stress has been reached, permanent deformation commences, and then proceeds almost regularly as the stress is increased. In the case of mild steel it is different, for, when deformation has once started, the metal continues to flow to a substantial extent without further increase of stress. These changes in mild steel correspond to what is known as the "yield point," which is revealed on the stress-strain diagram as a well-defined break or step. From time to time many different explanations have been advanced to account for the yield point in mild steel, but so far none of them

* Received August 31, 1942.

can be regarded as entirely satisfactory, though much light has been thrown on the subject during recent years.

Amongst the many interesting features connected with the yielding of mild steel are those which are usually described as the "upper" and "lower" yield points. These refer respectively to the stress at which yielding first begins and to the lower stress at which deformation will continue for as much as 2·0% or even more.

Winlock and Leiter (1) have shown that the value for the upper yield stress is affected by the rate of loading, and with very rapid loading this can become equal to the normal breaking stress of the material. It is also known that the general character of the stress-strain diagram is influenced by the type of the testing machine and by the way the test is carried out. Indeed Welter and Gochowski (2) go so far as to state that the upper and lower yield points are not reflections of the intrinsic qualities of the metal itself, but that they are merely caused by the inertia of the machine and are due to the sudden stretching of the specimen and the inability of the machine to react satisfactorily to this quick change. The work of Robertson and Cook,(3) however, proves that the upper and lower yield points in annealed mild steel are true features of the metal.

Rate of Loading and Character of Yield Point.

A few typical stress-strain diagrams of a low-carbon steel are shown in Fig. 1; they were taken under somewhat differing condi-

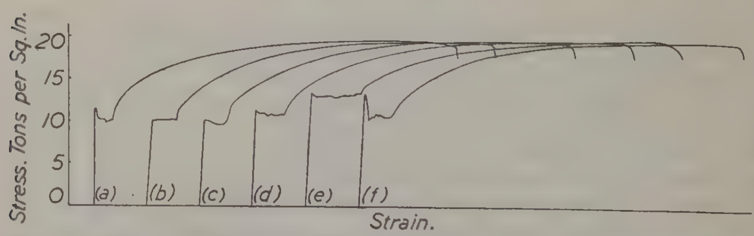

Fig. 1.—Influence of Varying Rates of Loading on the Character of the Yield Point of Mild Steel.

tions as regards speed, &c., and serve to illustrate how the form of the curve can be changed.

The data are given in Table I.; the chemical composition of the steel was as follows:

Carbon.	Manganese.	Phosphorus.	Sulphur.
0·025%	0·34%	0·01%	0·03%

Within the limits of the varying rates of loading used, the upper yield points range between 10·29 and 13·85 tons per sq. in. whilst the apparent lower yield points lie between 8·90 and 12·87 tons.

TABLE I.—*Mild Steel Annealed at* 950° *C. for* 1 *hr.*

Specimen Mark.	Rate of Loading. Lb. per hr.	Upper Yield Point. Tons per sq. in.	Lower Yield Point. Tons per sq. in.	Ultimate Stress. Tons per sq. in.
a	10	12·90 *	10·11	19·78
b	20, steadily continued throughout whole yield period.	10·29	10·29	19·68
c	20, but not so quickly as (*b*) during yield period.	10·29	9·74	19·77
d	6940	11·57	10·84	19·67
e	27,000, continued during yield period.	13·79	12·87	19·70
f	27,000, load allowed to drop during yield period.	13·85	8·90	19·71

* This high value is of some interest in view of the results dealing with the influence of slow rates of loading.

The observed differences in the ultimate breaking loads are well within the limits of experimental error.

With the rates of loading used for curve *b*, the yield point appeared to proceed to completion at a constant stress. This apparent absence of a lower yield point was due to the mechanism for applying the loading having been kept working at a rate which happened to coincide with the speed at which the specimen was stretching.

For the purpose of later considerations it will be useful to refer to two other sets of curves which were taken. These indicate how sensitive low-carbon steels are to variations in the rate of loading. The curves are shown in Figs. 2, 3 and 4, and the data are given in Tables II., III. and IV.

The curves in Fig. 2 were taken with samples originally of the same composition as the one just referred to, but in this instance the specimens were prepared as follows: Cold-drawn rods $\frac{7}{32}$ in. in dia. were heated to 950° C. in a stream of slightly moist hydrogen for five weeks to remove the carbon, and were then cold-drawn to $\frac{1}{8}$ in. in dia., annealed for an hour at 950° C. and slowly cooled in the furnace.

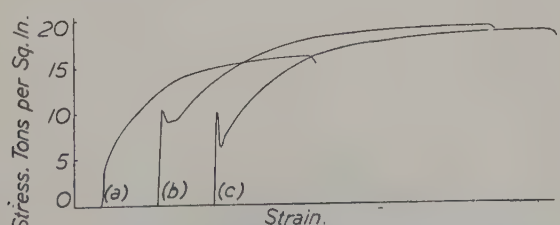

FIG. 2.—Influence of Varying Rates of Loading on the Yielding Behaviour of Decarburised Mild Steel.

TABLE II.—*Specimens Decarburised in Moist Hydrogen.*

Hydrogen-treated 5 weeks at 950° C., cold-drawn from $\frac{7}{32}$ to $\frac{1}{8}$ in. in dia., annealed 1 hr. at 950° C., furnace-cooled.

Specimen Mark.	Rate of Loading. Lb. per hr.	Elastic Limit. Tons per sq. in.	Upper Yield Point. Tons per sq. in.	Lower Yield Point. Tons per sq. in.	Ultimate Stress. Tons per sq. in.
a	160	4·51	...	...	16·55
b	27,000, continued during yield period.	10·46 (?)	10·46	9·30	18·92
c	27,000, load allowed to drop after yield started.	10·06 (?)	10·06	6·08	18·25

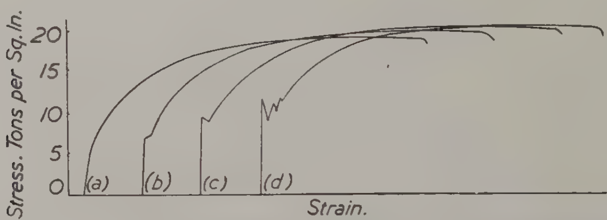

FIG. 3.—Influence of Varying Rates of Loading on the Yielding Behaviour of Titanium Steel.

TABLE III.—*Titanium Steel Annealed at* 1000° *C. for* 1 *hr.*

Specimen Mark.	Rate of Loading. Lb. per hr.	Elastic Limit. Tons per sq. in.	Upper Yield Point. Tons per sq. in.	Lower Yield Point. Tons per sq. in.	Ultimate Stress. Tons per sq. in.
a	100	5·86	...	...	19·60
b	300	...	6·73–7·31	...	19·98
c	6000 (approx.)	...	9·41	9·21	20·75
d	27,000	...	12·11	9·2 (approx.)	20·94

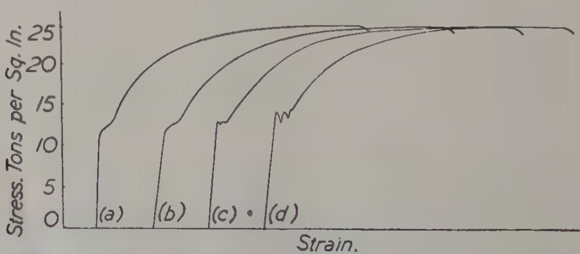

FIG. 4.—Influence of Varying Rates of Loading on the Yielding Behaviour of Nickel-Titanium Steel.

TABLE IV.—*Nickel-Titanium Steel Annealed at 950° C. for 1 hr.*

Specimen Mark.	Rate of Loading. Lb. per hr.	Elastic Limit. Tons per sq. in.	Upper Yield Point. Tons per sq. in.	Lower Yield Point. Tons per sq. in.	Ultimate Stress. Tons per sq. in.
a	60	11·56	...	...	25·14
b	300	12·11	...	...	25·09
c	300	13·17	13·17	...	25·09
d	27,000	?	14·61	?	24·99

The curves in Fig. 3 relate to a steel containing 0·025% of carbon and 0·14% of titanium, and those in Fig. 4 to a steel with 1·61% of nickel, 0·025% of carbon and 0·14% of titanium.

These results have been selected from amongst a large number because they indicate that specimens which give no yield point when tested at slow speeds may be made to show a yield point when tested at higher speeds. In passing, it may be noted that a steel containing the same nickel and carbon contents as that referred to in Table IV. but with no titanium gave a strain of 4·0% at the yield point. From this it is evident that mild steels are very sensitive to variations in the rates of tensile loading.

DIRECT-LOADING EXPERIMENTS.

Facts of the above kind appear to lend support to the view held by some writers that the yield point in mild steel may be due to some kind of retardation in the ability of the metal to react to increasing stresses and that time is necessary before plastic deformation can begin.

If this is correct it would seem reasonable to anticipate (*a*) that the upper yield point of mild steel should be lowered with decreasing rates of loading, and with very slow rates only a simple step should be found on the stress-strain diagram, and (*b*) that this in turn ought to become continuously lowered by still slower rates of loading. In other words, with extremely slow rates no yield point should be found. With this possibility in mind, a series of experiments was made to determine the influence of exceptionally slow rates of loading. For this purpose it was thought desirable to avoid mechanical devices for applying the loads; in this way difficulties from inertia arising from machine bearings, levers and other features of design would be overcome, and a constant load on the specimen could be maintained, or changed to any required value, immediately after yielding commenced. Accordingly, a simple arrangement for direct loading was used, Fig. 5. It consisted of a strong frame of four vertical supports fitted with a steel plate at the top, from which was suspended the upper grip attached to a universal joint; the lower end of the specimen was gripped in a similar manner, and below this second universal joint a pan was fitted for carrying the weights.

For the first set of experiments, specimens 13 in. long were cut from cold-drawn rods of approximately $\frac{1}{8}$ in. dia.; these were first straightened by giving them a small permanent set in a tensile machine, and then annealed at 950° C. in an inert atmosphere for an hour, followed by slow cooling in the furnace. The behaviour of the material under stress was observed by means of a Lamb extensometer. To bring the testing time within reasonable limits, an initial load of about 8 tons per sq. in. was applied in each case; this was substantially less than the elastic limit, when testing the same material at normal rates of loading in an Amsler machine. This initial load was slowly applied by cautiously releasing the jack supporting the pan carrying the weights. After taking the necessary extensometer readings, additional weights were carefully placed on the pan at predetermined intervals. The extensometer readings were taken for some time after each increase of load, because an appreciable time was required, after reaching the yield stress, before permanent deformation set in. Stretching was allowed to proceed to the extent of 0·0125%, which corresponded to a movement of 1 cm. on the scale. The load was then reduced by removing the weights at regular intervals, and during this period extensometer readings were again taken. Tests were made with different rates of loading, but the quickest speed was slow when compared with those used by Winlock and Leiter. The results obtained indicated that deformation continued at stresses much below those at which it started, but in only two of the experiments were the lower yield point stresses carefully determined. The evidence confirms Robertson and Cook's work and conclusions, that there are quite distinct upper and lower yield points in mild steel, and, from the nature of the present method of procedure, the behaviour cannot be attributed to inertia traceable to any mechanical device for applying the load. The results obtained are given in Table V., and illustrated in Fig. 6. There are indications of a general tendency for the upper yield stresses to become less with the decreasing rates of loading covered by the range between B and C

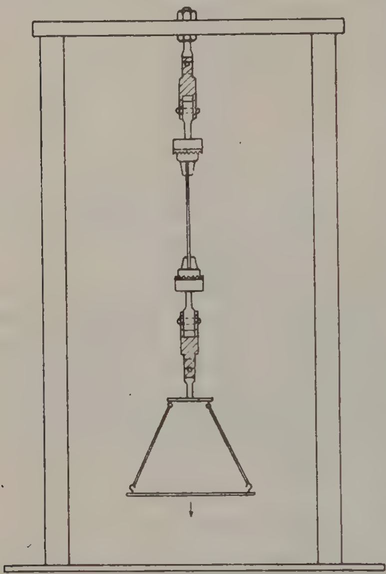

Fig. 5.—Equipment for Direct Loading.

TABLE V.—*Unshaped Specimens.*

Average area of specimens, 0·01214 sq. in.

Rate of Loading.			Upper Yield Point. Tons per sq. in.	Lower Yield Point. Tons per sq. in.	Remarks.
Lb. per hr.	Actual Rate in Testing.	Tons per sq. in. per hr.			
$\frac{1}{24}$	1 lb. per 24 hr.	0·00153	10·66	...	One addition of 1 lb. per day.
$\frac{1}{6}$	4 lb. per 24 hr.	0·00614	10·82	...	Eight ½ lb. additions between 9.0 A.M. and 5.0 P.M.
1	1 lb. per hr.	0·03678	9·62	...	
4	1 lb. per ¼ hr.	0·14712	9·43	...	
12	1 lb. per 5 min.	0·44064	9·51	...	
24	2 lb. per 5 min.	0·88272	9·49	...	
24	2 lb. per 5 min.	0·88416	9·28	8·58	1 lb. per min. off.*
24	1 lb. per 2·5 min.	0·89496	9·76	9·01	1 lb. per min. off.*
48	4 lb. per 5 min.	1·76256	9·62	...	
60	1 lb. per min.	2·20320	9·60	...	
120	2 lb. per min.	4·40640	9·98	...	

* Rate of unloading after reaching the yield point.

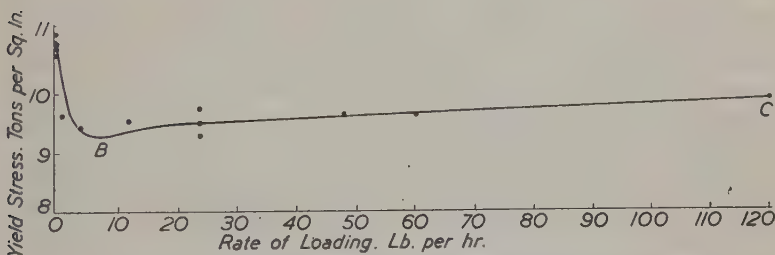

FIG. 6.—Influence of Rate of Loading on the Upper Yield Stresses of Unshaped Specimens of Mild Steel.

in Fig. 6. The differences are not large, and at first they might be considered to be within the range of experimental error, but on the other hand they are in conformity with Winlock and Leiter's work.

With still slower rates of loading than those represented by the point *B*, Fig. 6, there is a rise in the initial yield stress to about 10·7 tons per sq. in., as compared with approximately 9·6 tons per sq. in. for slightly quicker rates of loading. This result is not what would be expected from the supposition that the upper yield point is due to something in the nature of a lag caused by the material being capable of carrying a higher initial stress if insufficient time is given for plastic deformation to be initiated. It also provides a negative answer to the question raised earlier as to whether tests carried out with very slow rates of loading would yield evidence tending to indicate that no yield point would be shown in mild steel if extremely slow rates of loading were used. As previously stated, this series of tests was made with specimens of annealed drawn rods. That is to say, the diameter of the specimens was the

same over the whole length, including those parts in the grips of the testing machine. The yield almost always began immediately adjacent to the grips, and then spread over the length of the specimen; occasionally it was also observed to start at the points where the knife-edges of the extensometer were in contact with the specimen. Factors of this kind no doubt affect the upper yield stress, but it is difficult to see how they could give rise to the high values obtained for the very slow rates of loading. However, another series of tests, using the same steel, was made after shaping the specimens in accordance with the sketch, Fig. 7. In this way the

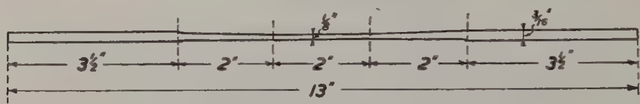

Fig. 7.—Dimensions of Shaped Specimens.

effects of the grips and the knife-edges of the extensometer were overcome, and the yielding was forced to commence within the shaped portion of the test-pieces. After machining, the specimens were annealed in an inert atmosphere for an hour at 950° C. and slowly cooled in the furnace. The tests were carried out in the same way as those previously described, but rather more care was taken during loading; each increase was made in the form of ½-lb. weights.

The results are given in Table VI. and plotted in Fig. 8. They confirm the essential features of the results previously obtained when using unshaped specimens. That is to say, they again show

Table VI.—*Shaped Specimens.*

Average area of specimens, 0·01139 sq. in.
Load increased by ½-lb. weights.

Rate of Loading.		Upper Yield Point. Tons per sq. in.	Lower Yield Point. Tons per sq. in.	Remarks.
Lb. per hr.	Tons per sq. in. per hr.			
2	0·07284	14·51	...	
2	0·07368	10·51	...	Slightly bent.
2	0·07394	10·79	...	
4	0·14096	9·09	...	
6	0·23684	9·33	...	
7·5	0·27180	12·26	...	
10	0·36840	9·39	9·01	1 lb. per min. off.*
15	0·57090	9·40	8·69	½ lb. per min. off.*
24	1·09704	8·66	8·32	½ lb. per min. off.*
30	1·12890	9·20	8·39	½ lb. per min. off.*
40	2·41600	9·18	8·34	½ lb. per min. off.*
120	4·29000	9·29	8·79	½ lb. per min. off.*

* Rate of unloading after reaching the yield point.

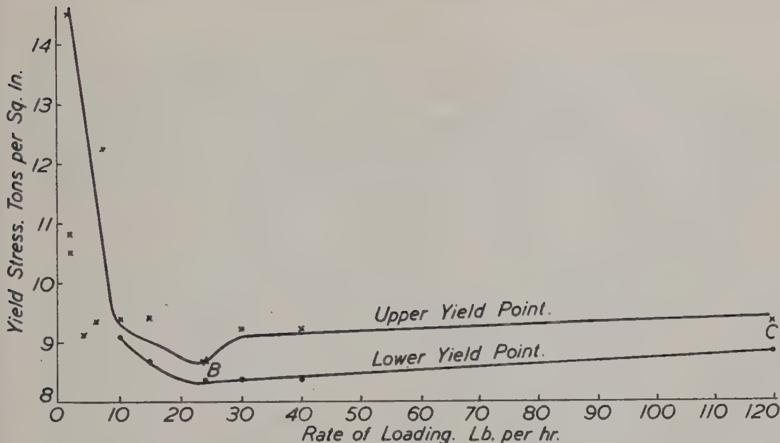

FIG. 8.—Influence of Rate of Loading on the Upper and Lower Yield Stresses of Shaped Specimens of Mild Steel.

a critical rate of loading below which the upper yield occurs at a higher stress than is needed for quicker and more normal rates. This critical rate appears to be approximately 10 lb. per hr. for shaped specimens. It is true that all the tests are not in accord with this conclusion, but this is not surprising when the circumstances are taken into account. In the over-stressed condition—that is, when the load is slowly applied and reaches a value above the normal yield stress—the material must be in a peculiarly sensitive state, and liable to yield suddenly as a result of some accidental small variation in the conditions of the test. The two recorded results for rates slower than that corresponding with the point B, Fig. 8 (which gave upper yield point stresses comparable with those obtained for quicker rates of loading), may be due to some variation of this kind. Be that as it may, the evidence indicates that with extremely slow rates of loading mild steel is capable of supporting stresses considerably higher than what the same material can withstand at ordinary testing speeds.

In this connection it is interesting to note that Professor Haigh obtained yield points in mild steel at loads as high as 118% of the ultimate tensile strength, whilst the elongation and the rest of the tensile curves were in no way abnormal. This high value of the yield point was obtained by preparing a tensile test-piece with the greatest care, using a highly polished surface and fillets of very large radii, and by loading the piece in such a way as to approach true axiality.

These observations have been confirmed by Professor F. W. Thorne in a paper read at the meeting of the British Association in 1931.[4]

Lower Yield Point.

As previously mentioned, whilst carrying out the above experiments on the influence of varying rates of testing by the method of dead-loading, the opportunity was taken to determine whether the existence of a lower yield was real, and not a reflection of the mechanical means used for applying the load. Some of the results are given in Table VI., and illustrated in Fig. 9. Extensometer

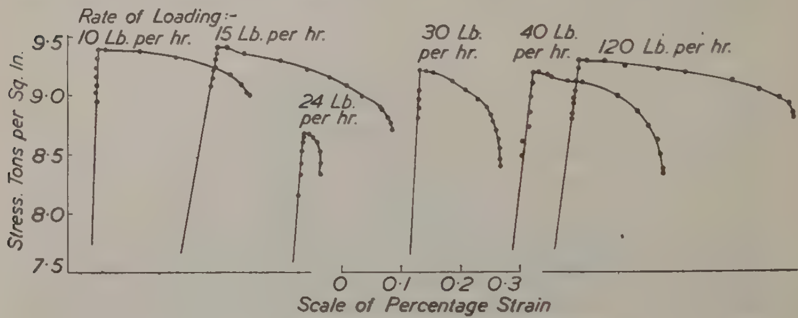

Fig. 9.—Influence of Rate of Loading.

readings were continued after the elastic limit had been reached, and during this stage the load was being reduced by constant amounts at definite intervals of time. From all these curves it will be seen that, once plastic deformation commenced, it continued at much lower loads than those initially required.

Unfortunately, the observations were not continued far enough to determine the exact stresses at which deformation came to an end. Hence, the recorded values for the lower yield points in Table VI. cannot be regarded as more than close approximations; the first two curves are not so complete as the others, because the readings were discontinued while deformation was proceeding rather quickly. Even in the last three instances the extensometer readings indicated that slow movement or creeping was still in progress. It is, therefore, only possible to suggest that the lower yields lie somewhere between 8·3 and 8·7 tons per square inch.

The Behaviour of Non-Ferrous Metals During Straining.

For many years it has been generally thought that those alloys which come within the broad description of "steels" were the only ones known to give clearly defined yield points during tensile testing. It is true that occasional references are to be found in the literature to the effect that some of the non-ferrous metals and alloys display this characteristic. One interesting example is Duralumin. There seems to be no doubt that a yield point has been observed by some

workers with this alloy,[5] whilst others have failed to detect one. This will be referred to again later. Another instance is to be found in a publication by Shoemaker,[6] in which is reproduced a series of stress-strain diagrams that reveal small indications of yield points for copper, and a 72/28 and a 60/40 brass when they were tested at low temperatures. With each of these materials the yield point shown on the curves increased as the testing temperature was lowered from 0° to −80° C.

Kuroda [7] repeated these experiments at low temperatures, but he obtained negative results. He suggested that the difference might be due to the fact that the materials used by Shoemaker contained appreciable quantities of impurities. The sample of copper was only about 99·75% pure, and the brasses had almost ½% of elements other than copper and zinc. Until quite recently it was generally thought that the yielding behaviour of mild steel during the initial stages of deformation was directly due to the element iron itself, but now it is known to arise from the presence of small quantities of other elements.[10] In view of this, it was considered to be a matter of much theoretical interest to extend the present investigation to an examination of a few non-ferrous materials to see if another metal would develop a yield point on the introduction of specially selected alloying elements and on suitable heat treatment. Any reliable evidence of this kind would help in furnishing a clearer conception of the way in which carbon and other elements act in ferrous alloys.

Nickel.

The first experiments were made with nickel. This selection was rather arbitrary, and perhaps the chief, if not the only, reason at the time was that it is close to iron in the periodic classification of the elements. Two samples were used, and these were supplied by the Research and Development Department of the Mond Nickel Co., Ltd. The approximate analyses were as follows:

	Malleable Nickel.	Manganic Nickel.
Carbon	0·01–0·02%	0·04–0·06%
Silicon	0·02–0·05%	0·10–0·15%
Copper	0·05–0·20%	0·10–0·20%
Iron	0·10–0·15%	0·10–0·15%
Manganese	Trace–0·03%	2·5 –2·8%
Magnesium	0·05–0·10%	0·05–0·10%

These samples were in the form of ¼-in. dia. cold-drawn rods, which were subsequently drawn down to ⅛ in. The specimens were then annealed at various temperatures for different periods, as indicated in Table VII., and tested in the Amsler machine. A constant rate of loading was used, namely, 10 lb. per min., unless otherwise stated, and the specimens were long enough to provide 6-in. gauge lengths for the stress-strain diagrams. The chief object of starting with heavily cold-worked samples was to ensure being able to obtain small crystals by annealing at suitably low temperatures.

The results obtained are given in Table VII. and plotted in Fig. 10. No useful purpose would be served by referring to the effects of

TABLE VII.—*Heavily Cold-Drawn Samples of Nickel and Manganic Nickel Annealed at Different Temperatures.*

Annealing Temp. and Time.	Elastic Limit. Tons per sq. in.	Yield Point. Tons per sq. in.	Yield Strain. %.	Ultimate Stress. Tons per sq. in.
		Malleable Nickel.		
300° C., 1 hr.	48·04	...	...	49·61
475° C., 1 hr.	41·68	...	...	47·87
500° C., 1 hr.	40·94	...	...	47·06
525° C., 1 hr.	39·73	...	...	47·32
550° C., 1 hr.	38·69	...	...	45·64
550° C., ½ hr.	39·09	...	...	45·98
600° C., 1 hr.	6·98	...	...	28·45
		Manganic Nickel.		
300° C., 1 hr.	70·37	...	...	74·16
475° C., 1 hr.	...	62·03	2·67	70·60
500° C., 1 hr.	...	61·51	2·67	69·37
525° C., 1 hr.	...	61·19	2·67	70·09
550° C., 1 hr.	59·43	...	...	67·82
550° C., ½ hr.	...	60·32	Only slight	68·89
600° C., 1 hr.	22·90	...	...	43·73

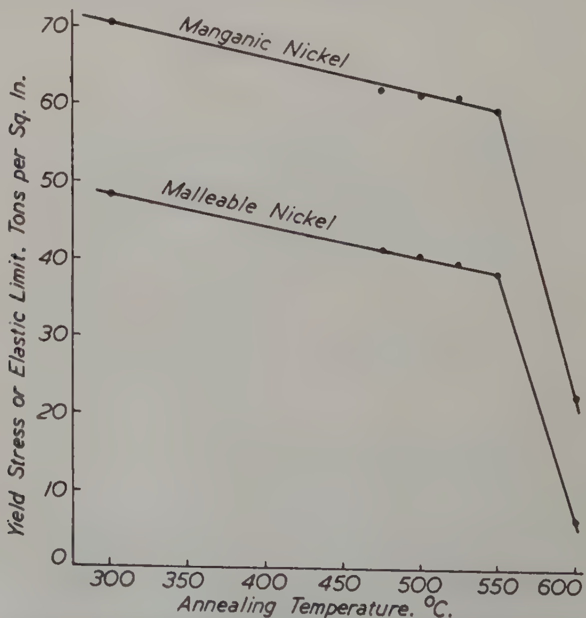

FIG. 10.—Influence of Annealing Temperature on Yielding Behaviour of Nickel.

varying annealing temperatures upon all the tensile properties, as the only feature of immediate interest is the behaviour of the two kinds of material during the early stages of deformation.

In no case did samples of malleable nickel give any sign of a yield point. The position was quite different with the manganic nickel, for in this instance well-defined yield points were obtained with samples which had been annealed at temperatures within the range 475–525° C. for 1 hr. After heating below or above this range of temperature no yield point could be detected. The upper limit of this range is below that at which the work-hardening is quickly removed. No yield point was observed after heating at 550° C. for 1 hr., but there were indications of a yield point after heating at the same temperature for only ½ hr.

The stress-strain curve for one of the samples containing manganese is shown in Fig. 11(*a*). The yield point was definite and gave a

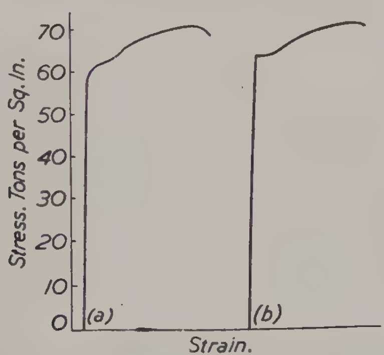

FIG. 11.—Stress-Strain Curves of Nickel Alloy, showing a yield point.

yield strain of 2·67%; it was more progressive in character than is usually obtained for mild steel. This was partly due to the slow rate of loading, which was 10 lb. per min. throughout the whole testing period.

Another sample of the same kind was tested with a quicker rate of loading, Fig. 11(*b*); the yield then occurred at a constant stress.

Having obtained these results with an alloy which largely consists of metal possessing a face-centred cubic lattice, it became even more desirable to find an alloy in which the element causing the change could be traced. In the light of what is now known concerning the influence of carbon in iron in this respect, attention was naturally turned to alloys constitutionally similar to those of the iron-carbon system; that is to say, those in which the added element forms solid solutions with a limited degree of solubility, coupled with a decreasing solubility with falling temperature. Many alloys of this kind behave like mild steel as regards the ability to

show age-hardening qualities after quenching from suitable temperatures, and some of them become age-hardened after straining, &c.

Up to the present, however, the authors have confined their attention to three cases, namely, standard silver, an alloy of copper with 1·85% of beryllium, and Duralumin.

Standard Silver.

The material used was supplied in the form of $\frac{1}{4}$-in. round cold-drawn rod, and this was further drawn to $\frac{1}{8}$ in. in dia. Samples were heated to 750° C. for $\frac{1}{2}$ hr. and then quenched in cold water.

Some of these were tested in the quenched state, whilst others were tempered by heating for $\frac{1}{2}$ hr. at 175°, 250°, and 500° C., respectively, and then tested. Another set of the quenched specimens was subjected to a tensile strain of 6·0% and then tempered at 175° C. for $\frac{1}{2}$ hr. The results are summarised in Table VIII.

TABLE VIII.—*Standard Silver.*

Treatment.		Stress to give 6% Strain. Tons per sq. in.	Limit of Proportionality. Tons per sq. in.	Yield Point. Tons per sq. in.	Ultimate Stress. Tons per sq. in.	Yield Strain. %.
Quenching and Straining.	Tempering.					
$\frac{1}{2}$ hr. at 750° C., quenched, not strained.	...	...	7·23	...	19·25	...
	$\frac{1}{2}$ hr. at 175° C.	...	12·15	...	23·19	...
	$\frac{1}{2}$ hr. at 250° C.	...	16·42	...	28·09	...
	$\frac{1}{2}$ hr. at 500° C.	...	14·45	...	21·42	...
Quenched from 750° C., strained 6%.	$\frac{1}{2}$ hr. at 175° C.	13·60	...	14·78	20·03	1·56
	1 hr. at 175° C.	13·30	...	14·62	20·27	1·50

None of the specimens which had been simply quenched, or quenched and tempered, gave any sign of a yield point. The stress-strain diagrams were typical of a non-ferrous metal or alloy. In the specimens that were quenched, strained, and then tempered, however, quite distinct yield points were obtained. A typical diagram for this group is shown in Fig. 12.

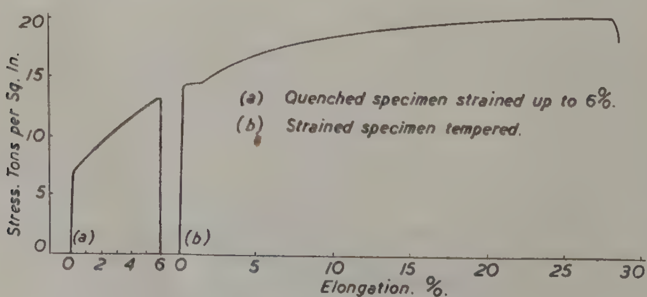

FIG. 12.—Standard Silver.

Copper-Beryllium.

The copper-beryllium alloy used contained 1·85% of beryllium, and was supplied in the form of $\frac{1}{4}$-in. drawn rods, in the soft or quenched condition. This was further drawn to $\frac{1}{8}$ in. in dia. by the authors. Some of the quenched samples were tested without further treatment, some after tempering at 200° C., and others after straining and then tempering. The results are incorporated in Table IX. This alloy gives a yield point under more widely

TABLE IX.—*Copper-Beryllium.*

Treatment.		Mechanical Properties.				
Heating, Quenching and Straining.	Tempering.	Stress to give 6% Strain. Tons per sq. in.	Limit of Proportionality. Tons per sq. in.	Yield Point. Tons per sq. in.	Ultimate Stress. Tons per sq. in.	Yield Strain. %.
(1) Heated to 600° C. for 15 min., cooled to 500° C. for 30 min., quenched	...	...	...	26·86	37·83	2·0
(2) As (1)	30 min. at 200° C.	...	...	26·70	37·66	1·9
(3) As (1) and strained 6%	30 min. at 200° C.	32·95	...	34·87	38·42	2·75
(1) Heated to 600° C., cooled to 400° C. for 30 min., quenched	...	...	...	29·63	39·82	1·75
(2) As (1)	30 min. at 200° C.	...	...	29·33	39·40	1·75
(3) As (1) and strained 6%	30 min. at 200° C.	34·71	...	36·01	39·40	2·00
(1) Heated to 700° C., slowly cooled in furnace	...	...	17·88	...	34·79	...
(2) As (1) and strained 6%	30 min. at 200° C.	30·23	...	32·90	37·45	3·0
(1) Heated to 800° C. for 30 min., quenched	...	...	...	12·03	...	0·75
(2) As (1) and strained 6%	16½ hr. at 200° C.	18·53	31·53 *	...*	42·26	...

* Faint indications of yield.

varied conditions of treatment than standard silver, and in many respects it behaves rather like mild steel. Thus, a yield point is obtained after heating to 600° C. and then quenching from 500° or 400° C., before and after tempering, and also after straining and tempering. It hardly seems necessary to discuss the results in detail at this stage, but it may be useful to draw attention to the varying amounts of strain at the yield point, namely, from 0·75% to as much as 3·0%, obtained after different treatments. The curves in Figs. 13 and 14 illustrate the kind of stress-strain diagrams obtained.

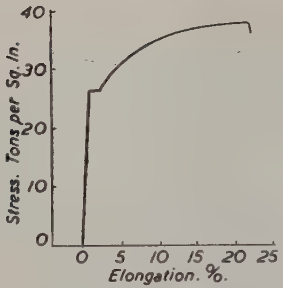

FIG. 13.—Copper-Beryllium, quenched and tempered.

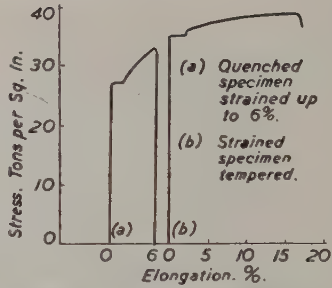

FIG. 14.—Copper-Beryllium.

Duralumin.

Although the authors' experiments with Duralumin gave negative results, they think it desirable to give a brief outline of what was done. Before doing so, however, it is of interest to point out that while the present investigation was in progress their attention was drawn to a recent paper by Sutoki [8] on the "serrated elongation" in different metals. On p. 685, a stress-strain diagram of Duralumin is shown which reveals a yield point. The specimen had been quenched in water from 400° C. followed by tempering at 140° C. for 8 hr. On repeating this heat treatment with the Duralumin at their disposal, the present authors were unable to detect any sign of a yield point. They made numerous other experiments by varying the quenching temperature and the tempering treatment, and in all cases their results were negative so far as the appearance of a yield point was concerned. A typical stress-strain diagram of one of the samples is shown in Fig. 15, where very

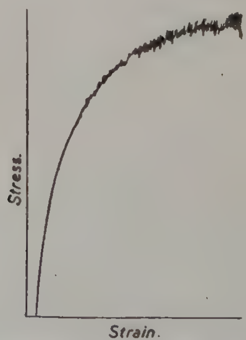

FIG. 15.—Typical Serrated Stress-Strain Diagram of Duralumin.

pronounced serration can be seen. This is the kind of curve which has been shown by Körber and Pomp [9] to be produced when mild

steel is tested at 250° C., *i.e.*, marked serration and no yield point. The authors think it is just possible that a serrated type of stress-strain diagram with no yield point when obtained by testing at one temperature might be associated with a set of conditions within the metal which will cause a yield point to appear when the test is conducted at a lower temperature, as in the case of mild steel. With this possible analogy in mind a specimen of heat-treated Duralumin was tested at −21° C., but again a negative result was obtained.

It was not possible to extend the range of these experiments, but the authors are still inclined to think that a yield point might be found in Duralumin, either by testing at a lower temperature or by varying the heat treatment or the composition of the alloy.

Discussion.

From the results obtained in the course of the present investigation it is evident that the quality of suddenly undergoing plastic deformation at a constant stress—that is, yielding—is not confined to ferrous materials. The same kind of change takes place in alloys of nickel, silver and copper, and there is every reason to believe that it will be found in many others.

The three metals just mentioned possess the face-centred cubic lattice type of structure, and, therefore, it seems reasonable to conclude that the yield point in iron-carbon alloys is not due to the metal having a body-centred structure. This is not intended to imply that the lattice structure of iron plays no part in increasing its tendency to give a yield point. It may be that a body-centred structure is more sensitive in this respect than a face-centred lattice by presenting a wider range of planes on which slipping can take place.

It has been shown by Edwards, Phillips and Jones [10] that the presence of minute quantities of carbon, and possibly other elements, causes iron to give a yield point.

Whilst the authors appreciate that the evidence available even now might not be sufficient to justify drawing definite conclusions concerning the precise manner in which the alloying elements cause the yield point to occur in metals, they think it is desirable to give a brief outline of their views in this connection.

Up to the present, perhaps the most satisfactory explanation of the yield point in steel is that which was put forward by Kuroda [7] and by Nádai.[11] Briefly, this rests on the hypothesis that, even when the amount of carbon present is extremely small, a honeycombed or cellular form of structure is obtained in which the soft crystals of ferrite are surrounded by ultramicroscopic films of hard carbide of iron. According to this conception the films enable the mass to support a stress well above that which the ferrite crystals themselves can withstand, and, in consequence, plastic deformation is prevented until these films are broken; but, once this takes place,

deformation of the ferrite must occur to quite an appreciable extent.

This view has the merit of being both reasonable and simple. In a recent paper Edwards, Phillips and Jones [10] suggested certain modifications, but the basic idea of strong crystal boundaries was retained.

Any explanation that is ultimately found to meet the case of mild steel will no doubt be sufficiently comprehensive to cover those non-ferrous alloys which behave in a similar way. That being so, it might be useful in the first place to examine the evidence obtained in the present investigation for standard silver and the copper-beryllium alloy. In both instances the equilibrium diagrams indicate that, at high temperatures, the alloys consist of homogeneous solid solutions, from which a second constituent separates on moderately slow cooling, and the separation proceeds more or less progressively as the temperature falls. In general form, the diagrams for these two systems closely resemble that of the iron-carbon alloys.

In the case of standard silver none of the samples in the condition as quenched from any temperature showed any sign of a yield point, but after the same treatment followed by straining and tempering well-defined yield points were observed. By heating to 750° C. and cooling to, say, 600° C. before quenching, ample opportunity is afforded for an appreciable amount of the second constituent to separate from solution. It therefore seems safe to conclude that (1) the normal separation of the second constituent, which in this case was a solid solution of silver in copper, with its tendency to migrate to the crystal boundary, did not give a yield point, and (2) the yield after straining and tempering was most probably due to the precipitation, or incipient precipitation, of the second constituent on the slip planes within the body of the crystals. This kind of change can no doubt be expected to proceed more readily and extensively at and near the crystal boundaries.

The results obtained with the copper-beryllium alloy are more complex than those for standard silver, for a yield point is obtained after much wider variations of treatment. The outstanding features of interest are:

(1) A yield point was found after quenching from each temperature, after quenching from 500° and 400° C. and tempering, and after quenching from the same temperatures, straining and tempering.

(2) No yield point was obtained with a specimen slowly cooled in the furnace from 700° C., but the same treatment followed by straining and tempering gave a large yield.

The former set of results calls for no special comment at the moment, because they are in very close agreement with what is known about mild steel. The results obtained after slow cooling

in the furnace are in many ways comparable with those of quenched standard silver. In all these cases no yield point was evident until after straining and ageing, in spite of the fact that ample opportunity was given for the separation of the second constituent, by cooling in the furnace on the one hand or cooling to the quenching temperature on the other. This seems to indicate that the yield point is not caused by a constituent which has already separated, as suggested by Kuroda, but by its incipient separation upon the slip planes within the crystals. Of course, the facility with which this precipitation takes place may be expected to vary (1) from one alloy system to another, and (2) with the degree of supersaturation of the solid solution and the mechanical treatment to which it is subjected before testing. With regard to the first, no doubt this will depend upon the particular atoms or compound molecules which are separating from solution. Concerning the second, what has just been said will also apply, but the speed of precipitation will tend to increase with greater degrees of supersaturation for a given system and set of conditions, as regards both temperature and the type of disturbance caused by mechanical deformation.

If these views are tentatively accepted as a basis of discussion, we may proceed to examine how they fit in with the experimental evidence now available. In the case of standard silver the solid solutions obtained by quenching from any temperature below 750° C. are not so unstable as to develop, spontaneously, the kind of precipitation on the slip planes which presumably causes the yield point. These solid solutions, however, can be stimulated, by straining followed by tempering, to develop that kind of precipitation which gives rise to a yield point.

The results for the copper-beryllium alloy are in most respects comparable with those for ordinary mild steels, but there is one outstanding difference which might be used to throw additional light on this intricate problem. Thus, by slow-cooling the copper-beryllium alloy in the furnace from 700° C., no yield point was obtained until the specimens were strained and annealed. Ordinary mild steels on the other hand always give a yield point after slow-cooling from, say, 950° C.

Before proceeding to account for these differences and offer an explanation of the yield point in metals which will embrace the known facts relating to both ferrous and non-ferrous alloys, it seems desirable to define the different conditions in which an added element that is capable of being held in solid solution to a greater extent at high than at low temperatures may exist after the alloy is cooled to ordinary temperatures.

In the first instance, however, it is important to bear in mind that solubility boundary lines in an equilibrium diagram are extremely difficult to determine experimentally for low ranges of temperature and concentration. In such cases the residual solid solution existing at the ordinary temperature, even after slow cooling, will almost

certainly be in a supersaturated condition. The degree of this supersaturation will vary from one alloy system to another, but in all there must be a tendency towards a state of equilibrium by precipitation of the excess material.

After the slow cooling of an alloy, the added element may exist in one or more of the following four conditions:

(1) In the form of a distinct and separate phase, either as the element itself, a new solid solution or a compound.

(2) Some will be held in the state of perfect solid solution which will be stable for all time.

(3) A portion may be forcibly retained in solution, but in an unstable state, and this may be capable of being partly or completely deposited from solution if the conditions become favourable.

Straining may increase the instability of this supersaturated state, and immediately cause the change to commence, but this change might need time or a rise in the temperature.

(4) After slow cooling, some of the atoms or compound molecules may have been rejected from solution on the slip planes at temperatures which are too low to permit of their coalescing to form distinct particles of the second constituent.

With some alloy systems, this transitional state of semi-precipitation may exist even after quick cooling, such as quenching from intermediate temperatures.

The amount of partially precipitated material will vary from one alloy system to another. In some, the rate of coalescence may be at least equal to that at which precipitation takes place, whilst in others this may not be the case.

Now, with the slowly cooled copper-beryllium alloy it would seem safe to assume that the solid solution is still supersaturated, but that all the atoms which have been thrown out of solution have coalesced to form the second constituent. Under these conditions no yield point can be observed during a tensile test. The instability of the supersaturated solid solution is, however, increased by straining, and when this treatment is followed by tempering a yield point is obtained. The authors consider that this is caused by the incipient precipitation of some of the dissolved substance on those planes of slip upon which deformation normally commences. In this way the initial resistance to plastic deformation is raised, but once the appropriate tensile stress has been reached, movement takes place on those planes, and then proceeds on subsidiary planes which have not been affected by the precipitation of atoms upon them. In other words, the elastic limit has been artificially raised by partial precipitation on those planes upon which preferential slipping would otherwise take place, but once this has started, deformation proceeds at a constant or even lower stress, because movement then occurs

on additional planes which have not been affected by the precipitation.

The above considerations involve the not unreasonable assumption that slipping must first begin upon a given set of planes before it can proceed upon a secondary set.

At this stage it may be useful to refer to experiments made not long ago by Edwards, Phillips and Jones [10] in their work dealing with the influence of titanium on various steels; a steel containing 1·6% of nickel and 0·025% of carbon showed a pronounced yield point on the stress-strain diagram, but another steel with the same nickel and carbon contents with 0·14% of titanium gave no yield point. Apart from the break in the diagrams corresponding to the yield point in the former, the two curves were quantitatively identical. From this it will be seen that the effect of carbon which has not been immobilised by the presence of titanium is simply to raise the stress at which deformation commences, but it has no influence on the straining behaviour of the metal beyond the yield point.

In the quenched specimens of the copper-beryllium alloy a yield point is obtained without the necessity of first straining and then tempering. This is explained on the grounds that, during quenching, partial precipitation of the atoms or molecules on the slip planes and their coalescence are taking place at the same time, but the amount precipitated is always in excess of that coalesced. Thus, at any given stage, there are always precipitated atoms on the planes of slip, and a yield point is produced.

In the case of specimens slowly cooled to the ordinary temperature, coalescence is complete, and therefore no yield point is obtained.

We may now turn to a brief consideration of mild steels, to see whether what is known about them concerning the yield point fits in with the above line of reasoning. As previously mentioned, the similarity between mild steel and the copper-beryllium alloy is almost complete. The only significant difference is that in all mild steels, &c., which have been slowly cooled a yield point is invariably found, whereas the copper-beryllium alloy after slow cooling does not show a yield point unless it is strained and tempered. Even this difference is more apparent than real, and the authors believe it is due to the exceptionally low degree of solid solubility of carbon in ferrite at low temperatures.

Experimental evidence in support of this view was obtained by Edwards, Jones and Walters,[12] but its significance was not appreciated at the time. After submitting samples of very low-carbon steels to a prolonged heating in moist hydrogen at 950° C., followed by slow cooling, they obtained no indication of a yield point on the stress-strain diagram; the same samples, however, after being strained in tension and tempered at 250° C. for 1 hr., gave a pronounced yield point. These facts have been confirmed by the present authors. This brings the behaviour of carbon in steel completely into line with that of beryllium in copper, and the

theoretical considerations put forward for the latter also apply to the former.

To explain the development of a yield point it is only necessary to postulate (1) that the prolonged heating of the low-carbon steel did not remove all the carbon and (2) that, although the amount of carbon left was small, it was still above the equilibrium limit of saturation in ferrite at low temperatures, and that this was capable of being precipitated on the slip planes by straining followed by tempering. The authors feel it is unnecessary to assume that in this case straining and tempering cause the migration and coalescence of the carbide of iron to the crystal boundaries of the ferrite. Indeed, it is difficult to imagine how this could be brought about in the course of an hour at such a low temperature as 250° C., or possibly less.

Conclusions.

(1) Experimental evidence has been obtained which confirms the conclusions of Cook and Robertson that low-carbon steels show an upper yield point at which plastic deformation commences and a lower yield point at which it will continue.

Stress-strain diagrams illustrate how the form of the curve obtained and, therefore, the apparent nature of yielding are affected by the speed at which the test is made.

(2) As previously indicated by Edwards, Phillips and Jones,[10] with specimens which have been almost completely decarburised, or in which the carbon is in combination with an element like titanium, no yield point is obtained when the test is carried out at normal slow rates of loading. When, however, the same specimens are tested by rapid loading there are indications of a small but distinct yield break on the stress-strain diagram.

(3) The yielding characteristic of mild steel is an intrinsic quality of the material and is not due to the mechanical devices of loading.

Both the upper and the lower yield points are quite clearly defined when a simple method of dead-loading is applied. This is true even when the rate of loading is extremely slow. Indeed, there are indications that the upper yield stress is raised by careful and very slow loading.

(4) Clearly defined yield points have been found in a nickel alloy, standard silver and a copper-beryllium alloy. The solvent metals of each of these alloys possess the face-centred lattice structure. From this and other facts referred to in the paper it is evident that the well-known yielding phenomena of mild steel cannot be attributed to the body-centred lattice of iron. The authors conclude that when a yield point is obtained, it is associated with the presence of an element which is capable of being held in solid solution to a greater degree at high than at low temperatures, and with a treatment which causes this element to be precipitated upon certain planes of slip within the crystals.

The authors wish to acknowledge that the foregoing investigation was carried out under the auspices of the South Wales Siemens Steel Association and the Welsh Sheet and Plate Manufacturers' Association.

They also wish to express their appreciation of the valuable help received from Mr. H. N. Jones, M.Sc.

REFERENCES.

(1) Winlock and Leiter: *Transactions of the American Society for Metals*, 1937, vol. 25, p. 1.
(2) Welter and Gochowski: *Metallurgia*, 1936, vol. 13, p. 183.
(3) Cook and Robertson: *Engineering*, 1911, vol. 92, p. 786.
Cook: *Proceedings of the Royal Society*, 1931, A, vol. 230, p. 103. *Transactions of the Institution of Engineers and Shipbuilders in Scotland*, 1937–38, vol. 81, p. 371.
(4) Docherty and Thorne: British Association for the Advancement of Science, Sept. 30, 1931: *Engineering*, 1931, vol. 132, Sept. 4, p. 295.
(5) Dawidenkow: *Zeitschrift für Physik*, 1930, vol. 61, p. 46.
(6) Shoemaker: *First Communications of the International Association for Testing Materials, Zurich*, 1930, p. 237.
(7) Kuroda: *Scientific Papers of the Institute of Physical and Chemical Research, Tokyo*, 1938, vol. 34, p. 1528.
(8) Sutoki: *Science Reports of the Tôhoku Imperial University*, 1941, vol. 19, July, p. 685.
(9) Körber and Pomp: *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1927, vol. 9, p. 346.
(10) Edwards, Phillips and Jones: *Journal of The Iron and Steel Institute*, 1940, No. II., p. 199 P.
(11) Nádai: "Plasticity." New York and London, 1931: McGraw-Hill Book Company.
(12) Edwards, Jones and Walters: *Journal of The Iron and Steel Institute*, 1939, No. I., p. 341 P.

CORRESPONDENCE.

Dr. E. W. Fell (Birmingham) wrote: Before discussing the paper in detail, I feel it is well to say, by way of introduction, that a large amount of work has already been carried out in the past on the remarkable yield point in steel and that, as a result, a very clear understanding of the phenomenon has been obtained, which, I believe, finds general acceptance. Very briefly, its explanation is simply that, owing to the properties of single iron crystals and of an aggregate of them, steel has certain properties such as greater strength than most non-ferrous metals, and, further, the yield point represents the general setting-in of plastic distortion. That this distortion may now proceed at a constant applied stress, or even lower stress, is understandable now that that original rigidity has been suddenly broken down, and the extent to which it occurs is attributed to the specially large number of slip planes available in iron crystals and their aggregates. The distortion is finally brought to a stop by work-hardening, and as slip has proceeded as far as it can, then a continual increase of applied stress is necessary for more extension to occur. This explanation was accepted by me in my work on yielding phenomena in metals.[1]

With regard to the present paper, I will confine myself to a consideration of the "precipitation" theories brought forward by the authors, according to which carbon is the cause of the yield point. At the outset, I must say that I find it very difficult to accept these explanations, as I believe that the high limit of proportionality and high modulus of elasticity of iron and steel are, primarily, properties of an aggregate of iron crystals, and are not due to the presence of carbon in any form whatever. It is necessary to explain why I refer in my discussion to the limit of proportionality and modulus of elasticity of iron and steel. It is for the reason that the authors in their Summary and Conclusions refer to a treatment which causes an element to be precipitated on certain planes of slip within the crystals of the metal as being associated with the occurrence of a yield point. According to this explanation, the effect of the precipitation is, presumably, at first to strengthen the metal to resist permanent deformation, but as the stress is still further increased there is reached, at last, a point at which this resistance is overcome and, in short, marked yielding occurs without further increase of stress now that there is nothing to resist it. Although the authors do not say so, their explanation implies that the high limit of proportionality and high modulus of elasticity of iron and steel are due to the precipitation. Although I believe that these two high values are important and necessary conditions for the yield point to occur in iron and steel, yet I believe that these high values are primarily due to the properties of iron crystals and their aggregates and are not directly associated with precipitation.

[1] Fell, *The Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1937, vol. 26, p. 160.

I consider that one of the chief obstacles in the way of hypotheses that carbon causes the yield point is the fact that the yield point is found in iron and steel which has been previously decarburised in hydrogen (Fell, *loc. cit.*, p. 157). This fact is confirmed by the curves (*b*) and (*c*) in Fig. 2, which show the yield point in mild steel decarburised by the authors. What evidence is there that the decarburising treatments applied did not result eventually in the complete removal of carbon from the iron? Supposing that any iron carbide remained in the iron after the treatments, then it seems improbable that such minute quantities of it should be the cause of the high values of the limit of proportionality and modulus of elasticity of iron or the cause of the occurrence of the yield point. Supposing for a moment that precipitation of carbon according to the authors does occur and is responsible for this strength and the yield point, then is it not astonishing that similar strength and a similar remarkable yield point as in iron are not encountered in normal routine testing of the non-ferrous metals, as, for example, of the cast and wrought alloys of aluminium in which so much use is made of precipitation phenomena for strengthening purposes? I mention this because there are very marked tendencies for precipitation-hardening to occur in aluminium alloys, given certain easily attainable conditions, yet in spite of this there is no yield point or high limit of proportionality or high modulus of elasticity as in iron and steel. Other non-ferrous alloys would also be expected to show precipitation-hardening to some extent in the general course, yet the same yield point is absent. It seems, therefore, that such a small amount of iron carbide in the iron would have a negligible effect on the properties of the iron, and what effect it might have may be certainly no greater than that of other impurities present.

Examples are given in the paper of yield points in a nickel alloy (Fig. 11), standard silver (Fig. 12) and copper-beryllium (Figs. 13 and 14) which resemble the yield points in iron and steel. These I attribute partly to the strengthening-up of the structure of the material by the special heat treatments and straining treatments applied, but the limit of proportionality and modulus of elasticity are apparently high. It would be interesting to know to what extent the plastic distortion at these yields resembles the Hartmann lines in iron. One way of doing this would be by observation of the distortion on bars having a high polish. I think that Young's modulus of elasticity should certainly be given in the paper with the limit of proportionality for the three non-ferrous alloys, because these two relatively high values together, plus the capability of the metal to deform plastically a considerable amount when its elastic limit is suddenly exceeded on increase of the applied stress, are, in my opinion, the true reason why the yield points occur as shown in the stress-strain diagrams referred to. The same reason applies, of course, for the remarkable yield point in iron and steel. In passing, it may be noted, for purposes of explanation, that a high-

tensile steel has high values for the first two of these properties but lacks, at any stress, that "extra" plasticity (due to a marked property of slip in crystals) which is necessary for a yield point to occur.

A stress-strain diagram of Duralumin is given in Fig. 15, showing a series of discontinuities in the curve. These are most probably yield points, and associated with the plastic distortion seen on polished surfaces of the same metal when under stress, which has been described in detail (Fell, *loc. cit.*, p. 147). I concluded that the distortion in iron at the yield point is essentially the same as this in Duralumin, but with important differences. For example, there is the difference that there is no single and extensive yield as in iron and steel. There are also considerably fewer types of slip plane in Duralumin than in iron, and it seems that as the applied stress is increased in alloys of the Duralumin type there is a succession of intermittent and permanent yields brought about by a small but finite amount of slip along the same crystal planes each time.

AUTHORS' REPLY.

Dr. Edwards and Mr. Phillips, in reply to Dr. Fell's communication, wrote: It is true that a large amount of work has been carried out in the past on the yield point in steel, but it is misleading to suggest that this has led to a clear understanding of the phenomenon. To emphasise that up to the present there is no explanation which is generally acceptable, it is only necessary to point out that numerous and widely differing views have been put forward during recent years. Thus, there are those advanced by Nádai, by Kuroda, by Andrew and Lee, by Morrison, by Welter and Gochowski, and by others.

The explanation acceptable to Dr. Fell for the yield point in iron is that iron differs from most non-ferrous metals in that it possesses greater strength and rigidity (as shown by a high limit of proportionality and a high modulus of elasticity) and that yielding is due to a sudden breakdown of this original inherent rigidity and the setting-in of plastic distortion, the extent of the distortion being attributable to the large number of slip-planes available in the body-centred lattice of iron crystals.

We do not regard this as a real explanation of the causes of the yield point in steel, but consider it to be simply a brief outline of a set of relevant facts which can be accepted without question because there is no need for any disagreement. A more fundamental question, however, is why have steel and almost pure iron what must be regarded as an artificially high elastic limit? The experimental evidence obtained in the present and our previous investigations provides an adequate answer to this question. There can be no doubt that this particular quality of a high though artificial elastic limit is due to the presence of traces of carbon and possibly

other elements. Further, it has also been clearly demonstrated that the yield point in steel cannot be attributed to the fact that α-iron has a body-centred crystal lattice, and therefore possesses a larger number of crystal planes (than face-centred crystals) upon which slip can take place. The reasons for this conclusion are: (i) When iron has been specially purified it does not show a yield point, though it still has the body-centred lattice; (ii) low-carbon steel which has not been decarburised, &c., does not display a yield point at, say, 500° C., at which temperature the carbon is in complete solution, even though the crystal structure is of the body-centred type at that temperature; and (iii) metals with a face-centred lattice have been shown to develop a yield point when certain additional elements are present.

We contend that pure iron, like most pure non-ferrous metals, has a low limit of proportionality and no yield point. This is true when the metal has been freed from such an element as carbon by decarburisation and when that element has been immobilised by the addition of a sufficient quantity of a strongly carbide-forming element such as titanium. We submit that the presence of a second element is necessary in iron and in other metals before yield-point phenomena are observed (*e.g.*, carbon in iron, copper in silver, manganese and magnesium in nickel, beryllium in copper, and copper, &c., in aluminium), and that this additional element has to be more soluble at high than at ordinary temperatures. Under certain conditions, the incipient precipitation of this second element (or its compound) on selective slip-planes of the parent metal imposes a greater rigidity on the metal and raises the limit of proportionality, thereby producing a steeper and longer rise in the initial portion of the stress-strain curve. When this extra rigidity is finally overcome, plastic deformation takes place at a constant or even at a lower stress, and the characteristic "step" or yield point is revealed on a stress-strain diagram.

Our contention that carbon in steel is the most effective element in causing the yield point is based on previous work by Edwards, Phillips and Jones,[1] in which it was shown that:

(*a*) Steels with no yield point could be produced by the addition of certain carbide-forming elements such as chromium, vanadium, niobium and titanium in a sufficient quantity to immobilise the carbon present, the amounts of the elements necessary being in inverse order of their affinity for carbon.

(*b*) On the addition of more carbon to a "yield-free" titanium steel, the yield point reappeared, while a further addition of titanium again removed the yield point.

It is impossible to explain these results by any theory based only on the crystallographic structure of pure body-centred iron. Further, yield points have been shown in the present paper to be produced in non-ferrous alloys in which the parent metals possess other

[1] *Journal of The Iron and Steel Institute*, 1940, No. II., p. 199 P.

types of crystal lattices, by methods analogous to those used for iron, namely, the addition of a second element followed by suitable heat treatment. In this respect, it is interesting to quote Dr. Fell's own views [1] that "there seems no reason why sudden and finite yielding should not occur in other metals if the conditions are suitable." We contend that we have determined the necessary conditions in certain cases.

It is interesting to record that during the yielding of these non-ferrous alloys the progress of the yield could be followed along the length of the specimens by observation of the gradual spreading of plastic deformation, just as in the case of steel.

Dr. Fell's objection to the carbon theory in the case of steel appears to be based on the results of his own work with specimens ($1\frac{1}{2}$ in. $\times$ $\frac{1}{2}$ in. $\times$ $\frac{1}{8}$ in.) treated with moist hydrogen for the relatively brief period of 136 hr. We suggest that decarburisation was not complete in this time. In our experiments with steel ($\frac{7}{32}$ in. in dia.) decarburised for 5 weeks (Fig. 2(*a*)) a complete absence of yield and, incidentally, a very low elastic limit are observable when normal conditions of loading are applied. At this stage, we would like to point out that we have every reason to believe that the ease and completeness with which carbon can be removed from steel by heating in an atmosphere of moist hydrogen varies with the character of the original steel. This is not surprising when the influence of varying quantities of carbide-forming elements is considered, but we believe that the quantity of oxygen present has a marked influence in this connection. Figs. 2(*b*) and 2(*c*), cited by Dr. Fell as confirmation of his own results, were intended merely to show, as was expressly stated in the paper, the influence of exceptionally fast loading in an Amsler machine on the character of the autographically recorded stress-strain curve. With normal rates of loading no yield point was obtained, *see* Fig. 2(*a*).

Regarding the influence of minute quantities of carbon, it may be remembered that Pfeil [2] found that a residual amount of 0·0025% of carbon produced noticeable effects on the ageing properties of decarburised iron, while Jay [3] has calculated that even 0·0002% would be sufficient to produce a cementite network, which presumably would affect the physical properties.

In that the constitution of Duralumin complies with the conditions stipulated in our theory, it might be expected that this alloy should show a yield point similar to that found in iron. That it nearly does so is indicated by its showing what have been described by Dr. Fell as a series of yields, and also by the similarity of its serrated stress-strain curve to that of iron tested in the blue-brittle range. We reaffirm our belief that, under certain conditions of heat and mechanical treatment and of temperature of testing, Duralumin can be made to show a yield point similar to that of iron.

[1] *The Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1937, vol. 26, p. 161.

[2] *Journal of The Iron and Steel Institute*, 1928, No. II., p. 167.

[3] *Journal of The Iron and Steel Institute*, 1940, No. II., p. 229 P.

TESSELLATED STRESSES.—PART I.[1]

By Dr. F. LÁSZLÓ (Engineering School, University, Melbourne, Australia).

Summary.

Anisotropy of the single crystals of most materials and the differences between the bulk physical properties of the components of compound solids readily cause internal self-compensated stress systems to develop round such centres as crystals or components of the compound structure, respectively. These self-compensated stress systems are called "tessellated stresses."

It is shown how to determine the order of magnitude of stresses due to crystal anisotropy. Those caused by differences in bulk properties are carefully investigated by the statistical application of the theory of elasticity.

A discussion is given of their influence on iron and steel, and some problems connected with other solids are mentioned.

General Considerations.

Most of the physical properties of single crystals of many materials vary with the crystallographic direction in which the properties are measured, but a body which consists of an aggregate of crystals with random orientations may be considered to be a quasi-isotropic body. When such an aggregate is subjected to "body-stresses," or to a change of temperature, a system of self-compensated "tessellated stresses" becomes superimposed on the body-stresses. The body-stress may be either an internal stress or the stress caused by an external load.

The magnitude and orientation of the local principal tessellated stresses depend on the orientation of neighbouring crystals, and their investigation would involve questions of probability. They must lie between certain maximum and minimum values, depending on the space configuration of the physical properties of the crystal.[2]

Tessellated stresses also develop in solids that consist of, or transform into, components which have different physical properties. Such stresses are called "structural tessellated stresses" to distinguish them from stresses due to anisotropy.

For bodies or portions of bodies which are quasi-isotropic from the structural point of view, the exact treatment becomes a very simple question of statistical investigation. If, however, the components of the structural tessellation are individually anisotropic, the maximum possible fluctuation of stress due to crystal anisotropy for a particular component must be superimposed on the stress

[1] Received February 3, 1942.

[2] E. Schmid and W. Boas, "Kristallplastizität," Fig. 154. Berlin, 1935: J. Springer.

found from the structural investigation. In some combinations, body-stresses, too, must be superimposed.

If tessellated stresses develop uniformly over the whole of a body, no body-stress effect can be involved. If they are confined to portions of a body, and are accompanied by a non-negligible change in volume, the body as a whole is subjected to certain body-stresses and strains.

In general, tessellated stresses form three-dimensional systems, and their investigation by direct measurement would involve great difficulties. For example, for stress measurements by X-ray diffraction methods it would be necessary for portions of the free surface of about 0·01 in. dia. to have nearly uniform values of tessellated stresses. Most metals are fine-grained, however, so that even structural types of tessellated stresses would not be revealed by X-ray diffraction. For this reason, all the subsequent discussion is based exclusively on the theory of elasticity and practical experiences.

In scientific publications on the physics of solids not much consideration is given even to the existence of tessellated stresses. Only vague references to internal stresses may occasionally be found.

List of Symbols and Some Definitions.

It will be convenient, and helpful to the reader if a complete list of symbols and definitions be made at this stage, although the definitions are explained more fully later:

d_1, d_2 = thickness fractions of the two laminated components—*see* Fig. 1.
u_1, u_2 = volume fractions of the two laminated components—*see* Fig. 1.
v_i, v_o = volume fractions of the inner and outer components of a compound sphere—*see* Fig. 2.
w_i, w_o = volume fractions of the inner and outer components of a compound cylinder—*see* Fig. 2.

($d_1 + d_2$, $u_1 + u_2$, $v_i + v_o$, $w_i + w_o$ each equal 1.)

y = volume fraction of cavities in a solid.
r_j, r_s = inner and outer radii of the outer component of a compound sphere or compound cylinder.
a_1, a_2 = linear coefficients of thermal expansion of the two materials forming a laminated slab—*see* Fig. 1.
a_i, a_o = linear coefficients of thermal expansion of the inner and outer material of a compound sphere or a compound cylinder—*see* Fig. 2.
t = increase of temperature (positive).
Δ = fractional increase of volume accompanying a phase change.
E = Young's modulus of elasticity.
m = reciprocal of Poisson's ratio.
f_1, f_2 = stresses in the components of a laminated slab.
$f_{a,i}, f_{a,o}$ = axial stresses in the inner and outer components of a compound cylinder.
$f_{t,oj}, f_{t,os}$ = tangential stresses in the outer component at j and s, respectively —*see* Fig. 2.
p = radial stress at the surface of contact of the two components in a compound sphere or a compound cylinder, and is also the tangential stress in the core of a compound cylinder and sphere.

$F_{red} = f' - \frac{1}{m}(f'' + f''')$, where f', f'', f''' are the principal stresses at a point and $f' \geq f'' \geq f'''$. This is termed the "maximum reduced tensile stress" at the point. It is evidently proportional to the maximum principal strain imposed on the material at that point, and is used as an index of the danger of crack formation in brittle material.

f_{red} = double the maximum shear stress at any point, and is given by the largest difference between the principal stresses at that point. It is a safe criterion of the danger of plastic yield of a ductile material, when compared with the yield strength of the material in plain tension. For both a compound sphere and a compound cylinder, the greatest value of f_{red} occurs at the inner surface of the outer shell, and for components having equal elastic constants it is:

$$f_{red, oj} = f_{t, oj} - p = \frac{mE}{m-1}(a_o - a_i)t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A)$$

It is assumed that the expression (A) would also represent the maximum value of f_{red} in a laminated slab, provided that the stress calculations could be made accurately. Consequently:

$\frac{mE}{m-1}(a_o - a_i)t$ or $\frac{mE}{m-1}(a_1 - a_2)t$ is termed the "*yield potential*" of tessellated stresses.

$\frac{m-1}{m}$ is termed the "*characteristic factor of stress relaxation*." It is shown that if the elastic constants of the two components are the same, the stresses in compound cylinders and laminated slabs are reduced in this proportion when they cut the surface of the body. It is then assumed that the same factor applies to compound spheres too.

$\epsilon_1, \epsilon_2, \beta_1, \beta_2, \beta_3$ = symbols to represent mathematical expressions which are given in the text.

$\gamma_f, \gamma_g, \gamma_c$ = densities of ferrite, graphite and cementite.

f_{fl}, f_{cl} = the stresses in ferrite or cementite lamellæ of pearlite in hypo- or hyper-eutectoid steels.

Sign Convention.—If a *rise* in temperature and an *increase* in volume accompanying a phase change are called positive, the sign convention is such that positive stresses are tensile and negative stresses are compressive. It is, of course, unnecessary to attach any meaning to the sign of f_{red} values.

Tessellated Stresses Due to Crystal Anisotropy.

The correct calculation, based on the theory of elasticity of crystals, and on the determination of groups of crystals such that tessellated stresses developed have maximum and minimum values, will not be attempted here; only the simplest estimate of their order of magnitude will be made.

(1) *Effect of Body-Stresses.*—The maximum and minimum values of the modulus of elasticity E of an iron crystal are $41{\cdot}2 \times 10^6$ and $19{\cdot}2 \times 10^6$ lb. per sq. in., respectively.[1] For mathematical simplicity, the following assumptions will be made, though most of them are not at all compatible with the elastic features of the crystal under consideration:

[1] W. Boas, *Journal of the Institution of Engineers, Australia*, 1940, vol. 12, pp. 147–152, Tables I. and III.

(*a*) An aggregate of iron crystals is subjected to homogeneous tension.

(*b*) The crystals are not at random, but have either of two definite orientations, *i.e.*, such that E has either a maximum or a minimum value parallel to the direction of body-tension.

(*c*) The volume fraction [1] of the crystals arranged in these two ways is such that the modulus of elasticity E of the aggregate in the direction of the body-tension is equal to that of a random aggregate of iron crystals, *i.e.*, $30{\cdot}5 \times 10^6$ lb. per sq. in.

(*d*) Crystals of each of the two groups are arranged to form minute prisms parallel to the direction of the body-tension, so that planes at right angles to this direction will be intersected at random by the two types of prisms.

(*e*) The lateral strains of the two types of prisms are equal. The tessellated stresses are then found to be:

$$100 \times \frac{41{\cdot}2 - 30{\cdot}5}{30{\cdot}5} = +\ 35\% \text{ and}$$

$$100 \times \frac{19{\cdot}2 - 30{\cdot}5}{30{\cdot}5} = -\ 37\%$$

of the actual primary tensile stress.

(2) *Effect of Temperature Change.*—Another cause of tessellated stresses due to crystal anisotropy is the variation of the coefficient of thermal expansion with direction. A rough calculation will be made to give the order of magnitude of the maximum and minimum values of such stresses in zinc. The following arbitrary assumptions will be made:

(*f*) All crystals are orientated to the direction of observation in either of two particular ways, *i.e.*, such that the stresses in them caused by any change of temperature are a maximum or a minimum in the direction of observation.

(*g*) The volume fractions of the crystals with each type of orientation are such that the coefficient of thermal expansion of the aggregate in the direction of observation is identical with that of a random aggregate of zinc crystals, *i.e.*, 30×10^{-6}.

(*h*) As in (*d*), but with the direction of observation substituted for the direction of the body-tension.

(*i*) As in (*e*).

The calculation, based on statements from the literature,[2] indicates that a rise in temperature of 1° C. causes the develop-

[1] Volume fraction $= \frac{1}{100} \times$ (volume percentage).

[2] Schmid and Boas, *loc. cit.*, p. 23, equation 10/4; p. 199, equation 58/1; p. 200, Table 18; pp. 202–203, Table 20.

ment of a maximum tensile stress of 274·5 lb. per sq. in. in minute prisms built up of crystals, the hexagonal axes of which make angles of 90° with the axes of the prisms, and of a maximum compressive stress of—173·5 lb. per sq. in. in the conjugate system of minute prisms, the crystals of which make an angle of 17° 20′ in the sense mentioned above. Tessellated stresses of this type develop independently of any other stress system.

Tessellated stresses due to crystal anisotropy are, in random aggregates, interwoven over the body, and are not self-compensated over single crystals or definite groups of crystals, though each single crystal may be considered as the centre of an individual stress system. Fragmentation of the body does not affect the tessellated stresses in the interior of the fragments. The surface layers both of a large body and of its fragments are affected by " surface intersections " in such a way that the tessellated stresses are reduced. The stress system is of a very complex nature if the body consists of crystals at random.

(3) A third type of tessellated stresses, due to crystal anisotropy, is that involved in magnetostriction; this, however, will not be considered further in this paper.

The effects of tessellated stresses due to crystal anisotropy on the properties of the body are manifold, *e.g.*, it is well established that there is a great reduction of hysteresis losses if the crystals of transformer-sheet metal are orientated parallel to each other and in the direction of the alternating magnetic flux.

There is little definite known about the order of the effect of tessellated stresses of the first two types on the physical and physico-chemical properties of materials. In this connection, four phenomena of technology, *viz.*, yield, formation of cracks, fatigue and corrosion, suggest themselves for investigation. As to yield, since the volumes subjected to the maximum value of such tessellated stresses are minute and scattered, there may be little detrimental effect. The other three phenomena deserve attention in future research, the respective properties of random aggregates being compared with those of more or less parallel-orientated aggregates, both being of fairly equivalent grain size.

Tessellated Stresses of Structural Type.

One type of structural tessellation may be idealised such that the body is considered to consist of laminated slabs, arranged with random orientation, the surface area of the lamellæ of each slab being large relative to their thickness.

If the feature of the structural tessellation is that one component is embedded at random in the other, *viz.*, the matrix, the latter should be imagined to be intersected at points equidistant from neighbour-

ing embedded components, which are supposed to be equal in volume. (The embedded components may be either homogeneous or compound units of a primary system.) The fragments obtained by the intersection should then be assumed to be replaced by the best compound sphere or compound cylinder of the same volume.[1] The statistical calculation is not affected by the actual dimensions of the units of the structural tessellation, obtained as above, but only by the statistical ratio of the dimensions of their components, which is expressed most suitably for the subsequent calculations by the volume fraction of the components of tessellation over the whole body or the portion of it under consideration.

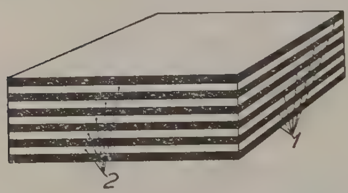

FIG. 1.—Lamellar Slab.

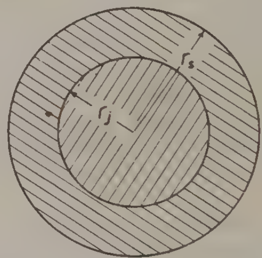

FIG. 2.—Cross-Section of a Spherical or Cylindrical Unit.

Fig. 1 shows a laminated slab consisting of components marked 1 and 2. The ratio of their volume fractions is equal to that of their thicknesses. Fig. 2 shows the core and shell of either a spherical or a cylindrical unit of tessellation, and the subscripts i and o will be used to distinguish the inner and outer material.

The volume fraction of the components, and, of course, of the portion of the body under consideration, are related as follows:

$$v_i : v_o : 1 = r_j^3 : (r_s^3 - r_j^3) : r_s^3 \text{ for the compound sphere,}$$
$$w_i : w_o : 1 = r_j^2 : (r_s^2 - r_j^2) : r_s^2 \text{ for the compound cylinder.}$$

If, at a certain temperature, compound units of tessellation be free from stresses, and the temperature be changed by $t°$ C., then structural tessellated stresses develop.

For laminated units, the correct calculation of their value would be fairly complex. It will, therefore, be assumed that direct stresses develop only in the planes of the lamellæ, and are constant over the thickness of a lamella and the same for every direction in the plane. This assumption hardly interferes with the statistical accuracy of the results.

[1] The most attractive proposition of a compound ellipsoid as the universal unit will not be discussed, because of its mathematical complexity.

The stresses developed in laminated units under these conditions are :

$$f_1 = -\frac{\epsilon_1\epsilon_2 u_2}{\epsilon_1 u_1 + \epsilon_2 u_2}(a_1 - a_2)t \quad . \quad . \quad . \quad (1)$$

$$f_2 = \frac{\epsilon_2\epsilon_1 u_1}{\epsilon_1 u_1 + \epsilon_2 u_2}(a_1 - a_2)t \quad . \quad . \quad . \quad (1)$$

where $\epsilon = \dfrac{mE}{m-1}$.

If the elastic constants of the two components are the same, *i.e.*, if $E = E_1 = E_2$ and $m = m_1 = m_2$:

$$f_1 = -\frac{mE}{m-1}u_2(a_1 - a_2)t \quad . \quad . \quad . \quad (1a)$$

$$f_2 = \frac{mE}{m-1}u_1(a_1 - a_2)t \quad . \quad . \quad . \quad (1a)$$

For compound spheres the problem can be completely solved by an elementary application of the theory of elasticity. In this case, the core portion i is subjected to hydrostatic strain by the radial stress p at the junction of the outer shell with the core. Two principal stresses of the outer shell, *i.e.*, those at right angles to the radius vector, are equal. They have a maximum magnitude $f_{t,oj}$ at r_j, and minimum magnitude $f_{t,os}$ at r_s, *i.e.*, at the junction of the components and at the outer surface, respectively. The third principal stress of the outer shell is radial, and is equal to p at r_j, and zero at r_s. The stresses in the compound sphere are as follows :

$$\begin{aligned} p &= \frac{1}{\dfrac{m_o-1}{2m_oE_o}\cdot\dfrac{1+2v_i}{v_o} + \dfrac{1}{m_oE_o} + \dfrac{m_i-2}{m_iE_i}}(a_o - a_i)t \\ &= \frac{-2v_o}{1+2v_i}f_{t,oj} \\ &= \frac{-2v_o}{3v_i}f_{t,os} \\ &= \frac{2v_o}{3}f_{red,oj} \quad . \quad . \quad . \quad (2) \end{aligned}$$

and if $E = E_o = E_i$, $m = m_o = m_i$:

$$\begin{aligned} p &= \frac{2mE}{3(m-1)}v_o(a_o - a_i)t \\ &= \frac{-2v_o}{1+2v_i}f_{t,oj} \\ &= \frac{-2v_o}{3v_i}f_{t,os} \\ &= \frac{2v_o}{3}f_{red,oj} \quad . \quad . \quad . \quad (2a) \end{aligned}$$

The problem of compound cylinders is again very complex, and an attempt should be made to obtain the correct solution by first solving the problem for the compound ellipsoid of revolution. For

simplicity's sake, it will be assumed that the axial stresses of each component are uniformly distributed over their respective cross-sectional areas, and that the axial, radial and tangential stresses are principal stresses; also the question as to the ends of the cylinder will be neglected. Neither of these arbitrary assumptions will noticeably affect the statistical correctness of the results and inferences.

Both the tangential and radial stresses of the core of a compound cylinder are invariably equal to p, the radial stress at the junction r_j of the two components. The stresses of the compound cylinder are found to be:

$$\begin{aligned} p &= \frac{\beta_2 + \beta_3}{\beta_1\beta_3 - 2\beta_2^2}(a_o - a_i)t \\ &= \frac{-w_o}{1 + w_i} f_{t,oj} \\ &= \frac{-w_o}{2w_i} f_{t,os} \\ &= \frac{w_o}{2} f_{red,oj} \quad \ldots \quad (3) \end{aligned}$$

$$f_{a,i} = \left(\frac{\beta_1}{\beta_2} \cdot \frac{\beta_2 + \beta_3}{\beta_1\beta_3 - 2\beta_2^2} - \frac{1}{\beta_2}\right)(a_o - a_i)t = \frac{-w_o}{w_i} f_{a,o} \quad \ldots \quad (3)$$

where
$$\beta_1 = \frac{m_i - 1}{m_i E_i} + \frac{1}{m_o E_o} + \frac{1 + w_i}{w_o E_o}$$
$$\beta_2 = \frac{1}{m_i E_i} + \frac{w_i}{w_o m_o E_o}$$
$$\beta_3 = \frac{1}{E_i} + \frac{w_i}{w_o E_o}$$

If $E = E_o = E_i$, and $m = m_o = m_i$:

$$\begin{aligned} p &= \frac{mE}{2(m-1)} w_o(a_o - a_i)t \\ &= \frac{-w_o}{1 + w_i} f_{t,oj} &&= \frac{-w_o}{2w_i} f_{t,os} \\ &= \frac{w_o}{2} f_{red,oj} &&= \frac{f_{a,i}}{2} \\ &= \frac{-w_o}{2w_i} f_{a,o} &&= f_{red,i} \quad \ldots \quad (3a) \end{aligned}$$

The value of $f_{red,i} = (f_{a,i} - p)$ is invariable over the whole core cylinder, and is consequently marked with one suffix i only.

The linear coefficient of the apparent thermal expansion of such compound units equals the sum of the linear coefficient of thermal expansion, a_o, of the outer component and the elastic strain per unit change of temperature at the outer surface of the unit. If the components have the same elastic constants, the bulk coefficient of linear thermal expansion is the same, in terms of the volume fractions, for all three units of tessellation considered, and is invariable with direction, *e.g.*:

$$a = v_i a_i + v_o a_o \quad \ldots \quad (4)$$

for the compound sphere. If the elastic properties of the components are different, the coefficient of thermal expansion of a tessellated body as a whole is not exactly equal to the fractional combination of the individual coefficients of its components.

If the elastic constants of the components are the same, double the maximum shear stress, $f_{red,oj}$, in the outer shell at r_j is given by the same expression for both the compound sphere and cylinder. Its independence of the volume fraction is noteworthy. It may be assumed that the correct calculation for laminated slabs would lead also to the same result. This value of $f_{red,oj} = \frac{mE}{m-1}(a_o - a_i)t$ may therefore be considered as the yield potential of tessellated stresses. The product $(a_o - a_i)t$ obviously ought to be termed the strain potential of structural tessellation, which is independent of the elastic properties and strength of the materials involved. It seems to be advantageous, for several reasons, to concentrate attention on the actual yield potential, not on the strain potential.

Units of tessellation at the outer surface of bodies are to be considered as intersected by the free surface and more or less relieved from their tessellated stresses. While all possible types of intersection are liable to occur with statistical frequency, consideration of certain characteristic modes of intersection may sufficiently indicate the order of possible tessellated stresses in the free surface.

If laminated units are intersected at right angles to the plane of the lamellæ, the stress in the surface is relieved so as to reduce the stress system to a one-dimensional case, and E is to be substituted for ε (*i.e.*, $mE/(m-1)$) in equations (1) and (1*a*). With components having the same elastic constants, $(m-1)/m$ accounts directly for the stress relaxation, and is called then the "characteristic factor of stress relaxation." It is equal to 0·7 for steel.

The calculation of the relaxation of the stresses in compound spheres would require too much mathematical effort, and will not be performed. To determine the stress relief in compound cylinders intersected by the free surface at right angles to their axes, consider that $f_{a,i} = f_{a,o} = 0$ in the surface layer; hence :

$$p = \frac{(a_o - a_i)t}{\frac{1 + w_i}{w_o E_o} + \frac{1}{m_o E_o} + \frac{m_i - 1}{m_i E_i}}$$

$$= \frac{-w_o}{1 + w_i} f_{t,oj}$$

$$= \frac{-w_o}{2w_i} f_{t,os}$$

$$= \frac{w_o}{2} f_{red,of} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

and for equal elastic constants:

$$p = \frac{E}{2} w_o(a_o - a_i)t$$
$$= \frac{-w_o}{1 + w_i} f_{t, oj}$$
$$= \frac{-w_o}{2w_i} f_{t, oj}$$
$$= \frac{w_o}{2} f_{red, oj} \quad \ldots \ldots \ldots \ldots \quad (5a)$$

On comparing equation (5*a*) with equation (3*a*), one sees that, when the components of the compound cylinder have the same elastic constants, the characteristic factor of stress relaxation is the same for laminated slabs and compound cylinders, *viz.*, $(m - 1)/m$ (equal to 0·7 for steel). Consequently, it is suggested that the same factor of $(m - 1)/m$ should be applied to elastically homogeneous compound spheres. The elastic relaxation, by intersection at the surface, of compound spheres with components having different elastic constants may be indicated by that of a compound cylinder having components in the same proportion.

Structural tessellated stresses may develop in solid units for reasons other than those considered above, *e.g.*, owing to a phase transformation at constant temperature of one of the components only, accompanied by its change in volume by the fraction Δ. In accordance with the sign convention, the following substitution should be made in equations (1) to (3):

$$(a_1 - a_2)t = \frac{\Delta_1}{3} = \frac{-\Delta_2}{3}\text{[1]}$$
$$(a_o - a_i)t = \frac{\Delta_o}{3} = \frac{-\Delta_i}{3} \quad \ldots \ldots \ldots \quad (6)$$

The phenomenon of the separation of gas in solid bodies and its concentration under high pressure in minute cavities of the body suggests the discussion of hollow units of tessellation. The body as a whole, or its affected portion, is to be considered as intersected at points equidistant from neighbouring cavities, the latter being assumed to be of equal volume. The fragments are re-shaped to form thick-walled spherical shells, corresponding to Fig. 2 with a hollow core of radius r_j. If an internal pressure p develops in such units, the stresses of the shell are connected with the internal pressure as follows:

$$p = -\frac{1 - y}{1 + 2y} 2f_{t,oj} = -\frac{1 - y}{3y} 2f_{t,os} = \frac{1 - y}{3} 2f_{red,oj} \quad \ldots \quad (7)$$

where y denotes the volume fraction of the cavities in the body.

[1] More accurately, $\left(\frac{\text{Specific volume of new phase}}{\text{Specific volume of old phase}}\right)^{\frac{1}{3}} - 1$. The author is indebted to Mr. T. F. Russell (English Steel Corporation, Ltd., Sheffield) for this improvement, and also for its application to all calculations concerned with phase transformation that were made by the author on the less accurate basis.

Stress concentration at surface irregularities of the cavities is to be added to the above values of the stresses in given cases.

If the separation of the gas takes place at a suitably low rate, all voids are exposed to the actual pressure potential of the process. With increasing rate of gas separation, the temporary pressure in the voids tends to develop proportionally to the ratio of the surface area to the volume of the void.

If voids are intersected when surfaces are machined, these voids are released from internal pressure, and the tessellated stresses of such surface units vanish. High internal pressure alone may rupture the voids and so relieve the stress in units which lie near the surface but are not intersected by it. A certain portion of the surface layer may, because of the internal pressure, be subjected to a process similar to the plastic expansion of a spongy material, *i.e.*, it may be

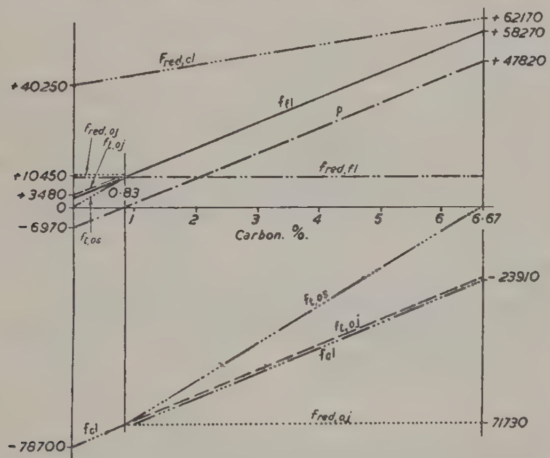

FIG. 3.—Tessellated Stresses, lb.per sq. in., in normalised steel.

expanded outwards in a direction at right angles to the surface. This may cause body-stresses too.

IRON AND STEEL.

Only plain alloys of iron and carbon will be discussed. Their elastic constants are approximately the same,[1] *i.e.*, $E = 30 \times 10^6$ lb. per sq. in. and $m = 10/3$. On applying equation (4), in combination with the least-square method,[2] to the bulk coefficients of thermal expansion of steels of 0·06—1·67% carbon content,[3] the

[1] F. T. Sisco, "The Alloys of Iron and Carbon," vol. II., "Properties," p. 583. New York, 1937 : McGraw Hill Book Co., Inc.

[2] The author is indebted to Miss E. B. Alexander, M.Sc., for this calculation.

[3] Sisco, *loc. cit.*, p. 575, Table 97.

individual coefficients of thermal expansion of iron and cementite of commercial purity are found to be:

$$a_f = 14{\cdot}98 \times 10^{-6}$$

and

$$a_c = 12{\cdot}16 \times 10^{-6}$$

respectively.

Fig. 3 shows the calculated [1] stresses which develop in normalised steel for a drop of temperature from 700° to 20° C., *i.e.*, of $t = -680°$ C.

Steel of eutectoid composition is considered as a laminated slab and, from equation (1*a*), the stresses in the ferrite and cementite lamellæ are found to be + 10,450 and − 71,730 lb. per sq. in., which we can designate f_1 and f_2, respectively, *i.e.*, these are the values of f_{fl} and f_{cl} for a 0·83% carbon steel. For hypo- or hyper eutectoid steels the pearlite grains are treated as though they were the cores of compound spheres, the outer shell of which is either ferrite or cementite, respectively. The stresses in the outer shell are calculated by equation (2*a*), and the relevant stresses are then suitably combined with those already present in the pearlite core to determine twice the shear stress on the ferrite lamellæ, $f_{red,fl}$, and on the free ferrite, $f_{red,oj}$, and the stress corresponding to the greatest strain on the cementite lamellæ, $F_{red,fl}$, and in the free cementite,

[1] The volume fractions concerned, and the coefficients of thermal expansion of the metallic matrix of a combination of graphite, cementite and iron are the following:

C = weight fraction ($= \frac{1}{100} \times$ weight percentage) of total carbon;
g = weight fraction of graphite;
c = weight fraction of carbon in cementite ($= 0{\cdot}0667$);
p = weight fraction of carbon in pearlite eutectoid ($= 0{\cdot}0083$);
$\gamma_f = 7{\cdot}864$ = density of iron;
$\gamma_g = 2{\cdot}25$ = density of graphite; $\gamma_c = 7{\cdot}67$ = density of cementite;

$$n_1 = c \, . \, \frac{\gamma_c}{\gamma_f}; \qquad n_2 = \frac{\gamma_f - \gamma_c}{\gamma_f};$$

$\dfrac{C}{n_1 + n_2 C}$ = volume fraction of cementite in steel;

$\dfrac{p}{n_1 + n_2 p}$ = volume fraction of cementite in pearlite;

$\dfrac{C}{p} \cdot \dfrac{n_1 + n_2 p}{n_1 + n_2 C}$ = volume fraction of pearlite in hypo-eutectoid steel;

$\dfrac{[n_1 - (1 - n_2)C] \, . \, [n_1 + n_2 p]}{[n_1 - (1 - n_2)p] \, . \, [n_1 + n_2 C]}$ = volume fraction of pearlite in hyper-eutectoid steel;

$\dfrac{n_1(1-g)g}{[n_1(1-g)^2 + n_2(C-g)]\dfrac{\gamma_g}{\gamma_f} + n_1(1-g)g}$ = volume fraction of graphite in a combination of iron, cementite and graphite.

$\dfrac{[n_1(1-g)^2 - (1-n_2)(C-g)]a_f + (C-g)a_c}{n_1(1-g)^2 + n_2(C-g)}$ = linear coefficient of thermal expansion of the metallic matrix of a combination of iron, graphite and cementite.

$F_{red,oj}$. Under the assumptions made, it is found that when the stress p at the junction of the components of this spherical system is superimposed upon the stresses of the "free" laminated slabs, *i.e.*, the stresses in the ferrite and cementite of a eutectoid steel, the result is that :

(1) $f_{t,oj}$ of a ferrite matrix is the resulting stress f_{fl} of ferrite lamellæ.

(2) $f_{red,oj}$ of a ferrite matrix is the $f_{red,fl}$ of ferrite lamellæ.

(3) $f_{t,oj}$ of a cementite matrix is the f_{cl} of cementite lamellæ.

(4) $F_{red,oj}$ of a cementite matrix is the $F_{red,cl}$ of cementite lamellæ.

All the stress values, except F_{red}, are therefore obtainable from equation (2); the F_{red} values are obtained by combining principal stresses as already described.

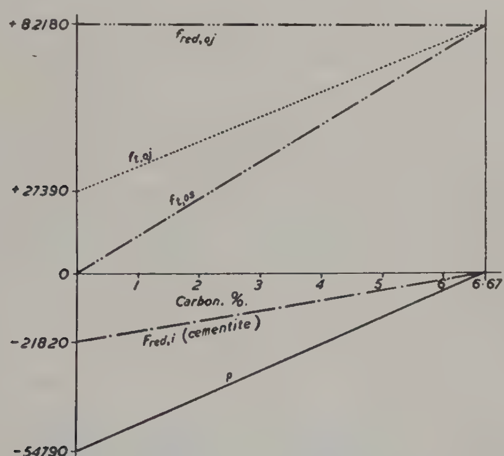

FIG. 4.—Tessellated Stresses, lb. per sq. in., in spheroidised steel.

The value of $f_{red,fl}$ is independent of the volume fraction, *i.e.*, it is independent of the carbon percentage, and its magnitude of 10,450 lb. per sq. in. guarantees that plastic deformation of ferrite would not occur in normalised steel. While $F_{red,cl} = F_{red,oj}$ increases to the value of + 62,170 lb. per sq. in. when the carbon content reaches 6·67%, this *reduced tensile stress* is moderate enough at any high commercial carbon percentage for there to be no danger of the formation of cracks in the brittle cementite of normalised steel. If, however, the normalised steel is subjected to external tensile stresses, the formation of cracks in the cementite is encouraged by the locked-up reduced stress $F_{red,cl}$.

The tessellated stresses of spheroidised steel, corresponding to the same drop of temperature of 680° C., are given in Fig. 4; they were calculated for a plain spherical system with a cementite core

and a matrix of ferrite. The brittle cementite core is always under a hydrostatic pressure p such that its reduced "tensile" stress $F_{red,c}$ is compressive, increasing from $-21{,}820$ to 0 as the carbon content increases from 0 to 6·67%. The yield potential of the ferrite matrix is independent of the carbon percentage, and its value $f_{red,oj} = 82{,}180$ indicates that the ferrite matrix of spheroidised steel certainly yields during cooling down, thus relieving also the stress in the cementite core. The degree of plastic yield can scarcely be estimated, since the ferrite may exhibit a certain super-elasticity under the actual stress concentration at r_j. The plastic yield of the ferrite matrix is limited, at low and medium carbon concentrations, to a thin internal layer of the spherical shell.[1] Since $f_{red,os} = f_{t,os}$, there should be more than 2% of carbon in the steel, giving $f_{red,os}$ equal to about 25,000 lb. per sq. in., in order to cause the ferrite matrix to yield as a whole.

If plain carbon steel is cooled at such a rate that the pearlite transformation is just not frustrated, the temperature of the transformation may drop down to 665° C.[2] This would reduce the stresses shown in Figs. 3 and 4 by not more than 5%.

If the steel is normalised with a low cooling rate, the stresses due to structural tessellation develop about as gradually as the yield resistance of the material. The ratio of the actual stress to the actual yield resistance may, at a certain range of temperature, be unfavourably high, and cause a reduction in the final stresses. This effect cannot be fully combined with that of quick cooling.

Possible error in the calculated stresses, due to errors in the values calculated for a_f and a_c, is determined to be $-2{\cdot}8\%$ to $+3{\cdot}2\%$. The results of Figs. 3 and 4 are, therefore, correct to within at least $\pm 10\%$.

The characteristic factor of stress relief of surface units is, of course, $(m-1)/m = 0{\cdot}7$.

Graphite forms either a lamellar or a spherical system of tessellation with the metallic matrix. The stresses of these systems are to be superimposed on those of the matrix, the latter corresponding to either Fig. 3 or Fig. 4. The elastic constants of graphite and its coefficient of thermal expansion are stated to be : $E = 1{\cdot}194 \times 10^6$ lb. per sq. in.[3]; $m < 2{\cdot}18$[4]; $a_g = \dfrac{(2 \times 3{\cdot}7) + 2{\cdot}7}{3} \times 10^{-6} = 3{\cdot}37 \times 10^{-6}$.[5] The possible variation of m from 2·18 to 2·0 would

[1] Stodola-Löwenstein, "Steam and Gas Turbines," vol. II., pp. 1082–1083 (hole in an infinitely extended plate). New York, 1927 : McGraw Hill Book Co., Inc.

[2] S. Epstein, "The Alloys of Iron and Carbon," vol. I., "Constitution," p. 167, Fig. 43. New York, 1936 : McGraw Hill Book Co., Inc.

[3] Landolt-Börnstein, "Physikalisch-Chemische Tabellen," Zweiter Ergänzungsband, p. 25. Berlin, 1931 : J. Springer.

[4] Landolt-Börnstein, *loc. cit.*, Erster Ergänzungsband, p. 24. Berlin, 1927 : J. Springer.

[5] Landolt-Börnstein, *loc. cit.*, Zweiter Ergänzungsband, p. 1151.

cause the stresses in low-graphite spherical systems to be increased in the ratio 1 : 4·18.

Grey cast iron will be considered as a special lamellar system of tessellation such that hydrostatic locked-up effects cannot develop, and two-dimensional stresses are set up in the graphite and the metallic matrix, in the planes of the lamellæ, according to equation (1). The stresses have been calculated for three significant types of the metallic matrix, *viz.*, ferrite, pearlite eutectoid and cementite, and for graphite weight-percentages increasing from zero to 6·67%. The results, for a drop in temperature of 680° C., have been expressed by linear equations in terms of the weight-percentage of graphite. The error is not more than $\pm$ 2·5% for amounts of graphite varying from 0 to 4% by weight. The uncertainty of m does not affect the results considerably for lamellar graphite. These results, tabulated in the upper half of Table I., show that the stresses to be superimposed on those of the metallic matrix are almost negligible, thus indicating a great advantage of the lamellar form of graphite in cast iron.

Temper carbon is fairly spherical in shape. The linear equations for the stresses due to a drop in temperature of, again, 680° C. of spherical graphite in matrices of iron, pearlite and cementite are derived by the above method, and are shown in the lower half of Table I. The error is about $\pm$ 2·5% over the range of 0–4% of graphite. The enormous differences between the yield potentials of lamellar and spherical systems, *i.e.*, 17,400 as against 130,500 for $m = 2{\cdot}18$, or 18,850 as against 546,000 for $m = 2{\cdot}0$, readily explain the trend towards the formation of random lamellæ of graphite during solidification, and why the resistance to the decomposition of iron carbide becomes the more reduced the more thoroughly and intensively the metallic matrix has been intersected at random by graphite lamellæ.

It appears that numerical considerations would be unreasonable in connection with the spherical system until the value of m has been definitely ascertained. Greater real stresses cannot develop, during cooling, than are compatible with the gradually increasing yield resistance of the metallic matrix, the latter governing the portion of the strain potential being converted into tessellated yield.

In superposition of the spherical tessellated stresses of Table I. on other tessellated stresses of the metallic matrix, either the stress $f_{t,os}$ or $-p\,\dfrac{v_i^{\frac{1}{3}}}{1 - v_i^{\frac{1}{3}}}$, modified according to the actual redistribution, is to be superimposed from the statistical point of view, the former being less, the latter probably greater than the effective value. In certain special cases, the redistributed value of $f_{t,o}$ is of significance.

If cementite decomposes to ferrite and graphite at constant temperature the tessellated strain potential is 0·0439. Though the process can be realised only at high temperatures, at which the yield resistance of the metallic matrix tends to be negligibly small, the

reluctance of the metallic matrix to undergo this enormously great tessellated strain of tensile character seems to explain why :

(*a*) Carbon tends to separate from supersaturated solid solution, at moderate temperatures and under normal conditions, as the unstable cementite.

(*b*) Cementite embedded in iron is much more stable than it is when isolated.

(*c*) The graphitisation of malleable cast iron is a more or less cumbersome process, inversely to the amount of vigorous agitators of decomposition, as silicon and others, present.

TABLE I.—*Tessellated Stresses, lb. per sq. in., with Graphite, g% by Weight, Embedded in a Matrix of Iron and/or Cementite.*

Description.		Matrix consisting of— Iron.	Pearlite.	Cementite.
Stress in graphite lamellæ	$m_g = 2{\cdot}18$	$-17{,}400 + 37{\cdot}5 \times g$	$\times \frac{11{\cdot}25}{11{\cdot}61}$	$\times \frac{8{\cdot}79}{11{\cdot}61}$
	$m_g = 2$	$-18{,}850 + 40 \times g$		
Stress in metallic matrix	$m_g = 2{\cdot}18$	$630 \times g$		
	$m_g = 2$	$680 \times g$		
Characteristic factor of stress relaxation at surface intersections	$m_g = 2{\cdot}18$	0·54	0·54	0·54
	$m_g = 2$	0·5	0·5	0·5
Hydrostatic pressure, p, on spherical graphite embedded in metallic matrix	$m_g = 2{\cdot}18$	$-87{,}000 + 1{,}150 \times g$	$\times \frac{11{\cdot}25}{11{\cdot}61}$	$\times \frac{8{\cdot}79}{11{\cdot}61}$
	$m_g = 2$	$-364{,}000 + 17{,}500 \times g$		
Stresses in metallic matrix	$f_{t,oj}$	$-p \times \frac{1 + 0{\cdot}066 \times g}{2 - 0{\cdot}066 \times g}$		
	$f_{t,os}$	$-p \times \frac{0{\cdot}1 \times g}{2 - 0{\cdot}066 \times g}$		
	$f_{red,oj}$	$-p \times \frac{3}{2 - 0{\cdot}066 \times g}$		
Characteristic factor of stress relaxation at surface intersections	$m_g = 2{\cdot}18$	$0{\cdot}2055 \approx \frac{1}{5}$	0·2055	0·2055
	$m_g = 2$	$0{\cdot}0643 \approx \frac{1}{15}$	0·0643	0·0643

Furthermore, it should be expected that the graphitisation of homogeneous steel would commence in, and tend to be confined to, the surface layer, which may increase in volume with the development of least pressure opposing the separation of graphite.

The formation of cementite by the carburisation of iron involves a tessellated strain potential of about 0·0318, having tensile effect on the matrix. One reason why cementite is formed is that the deposition of graphite would be connected with a tessellated strain potential very much in excess of the very great value of 0·0318. Since the resistance of the matrix against permanent tessellated tensile strains increases towards the interior, it contributes to the difficulty of carburising surface layers as they increase in thickness.

Similar considerations suggest themselves in connection with nitriding.

Effective agitation during the formation or re-shaping of a

structural component by annealing may be provided by alternate heating and cooling, *i.e.*, pulsating heating. One of the temperature limits, the quick change-over from which to the other develops tessellated stresses of agitating character, should of course be such that it relieves existing tessellated stresses fairly quickly.

Hardening of Steel.

Let us consider a plain carbon steel of about 1·2% carbon content quenched from 750° C. to, and maintained at, about 125° C. After a certain time of rest, single martensite needles gradually develop at random.[1] The result may be regarded as core cylinders of α-martensite embedded in a matrix of austenite. The specific volumes

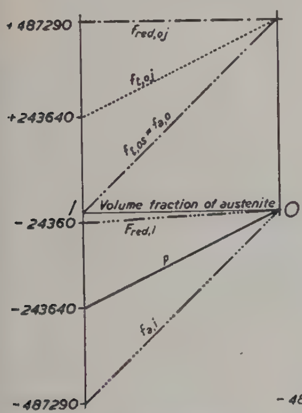

FIG. 5.—Cylindrical core of martensite.

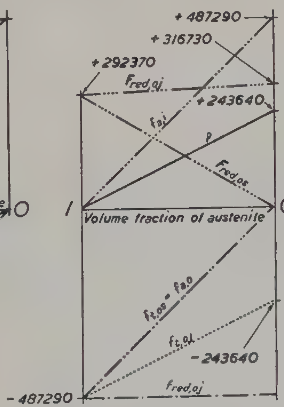

FIG. 6.—Cylindrical core of austenite.

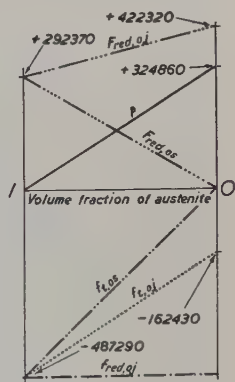

FIG. 7.—Spherical core of austenite.

FIGS. 5 to 7.—Tessellated Stresses, lb. per sq. in., due to hardening of steel.

of the different phases of a plain 0·9% carbon steel are given by Sisco [2]; those for austenite and α-martensite are 0·1275 and 0·1319, respectively. Hence, if these phases be assumed to have the same elastic constants, the strain potential is 0·01137 and the stress potential 487,290 lb. per sq. in. The stresses are shown in Fig. 5 plotted against the gradually decreasing volume fraction A of retained austenite. As the yield resistance of austenite is a fairly small fraction of the actual yield potential, plastic yielding will take place and the whole stress level will be reduced, the more so the slower the transformation, as there is more time for plastic yielding to occur.

After the transformation has proceeded for a certain time, martensite forms a continuous structure like a honeycomb, enclosing

[1] Epstein, *loc. cit.*, p. 177, Wiester's experiment.
[2] Sisco, *loc. cit.*, p. 570.

retained austenite cores of more or less irregular shape. For this intermediate stage, which is regarded as a cylindrical system with austenite cores and a matrix of martensite, Fig. 5 is no longer valid, and the character of the stress conditions will now be as shown in Fig. 6. At the end of the transformation there is still retained a certain amount of austenite approximating to minute spheres embedded in martensite.[1] Fig. 7 shows the stresses calculated for this condition. Though all three diagrams are completed for volume fractions of from 0 to 1 of austenite, they should be considered only over the range of what appears to be their possible validity.

Nascent martensite is, no doubt, plastic, with a certain unknown yield resistance. During the first phase of the transformation (Fig. 5) the yield potential of the austenitic shell remains constant at 487,290 lb. per sq. in., and that of the martensitic cylindrical core has a maximum value of 243,640 lb. per sq. in., which suggests that only the austenite may yield. During the next phase (Fig. 6), the yield potential will be constant at 487,290 lb. per sq. in. for the nascent martensitic matrix, and a maximum of 243,640 lb. per sq. in. for the then existing austenite cores. The yield resistance of austenite may be assumed to be of the order of 100,000 lb. per sq. in. at 125° C., whilst no reasonable estimate can be made for that of nascent martensite, so it is possible that either or both yield during this period. Fig. 7 illustrates that during the final phase of the transformation the yield potentials are 0 and 487,290 lb. per sq. in. for the retained austenite and the nascent martensite, respectively; thus any plastic yield must occur in the latter. The yield resistance Z of nascent martensite therefore governs the finally resulting tessellated stresses, which may be indicated by multiplying the figures of Fig. 7 by the factor $Z:487{,}290$, although it must be remembered that $f_{t,os}$ is reduced by less than $f_{t,oj}$.

It is apparent that during the whole process the retained austenite is under great tension due to the tessellated stresses, which could not therefore account for the remarkable phenomenon of the retention of austenite.

If the metal is assumed, by some process, to be thoroughly relieved from tessellated stresses at some intermediate stage when the volume fraction of core cylinders of austenite is A_m (Fig. 6), and to complete its transformation to a final volume fraction of austenite $A < A_m$, the resulting stress conditions are characterised once more by Fig. 7, if its ordinates are reduced by the factor $\dfrac{A_m - A}{1 - A}$. Consequently it is recognised that tessellated stresses due to the martensite transformation have an unvarying tendency to complete the transformation, thus assisting the effort due to the free energy of martensite being less at 125° C. than that of austenite.

On quenching austenite from 750° to about 125° C., compressive

[1] Epstein, *loc. cit.*, p. 263, Fig. 101.

body-stresses of the order of about 100,000 lb. per sq. in. develop in the outer shell, and much greater tension in the core. These body-stresses are certainly redistributed, more or less, during a slow transformation, since they combine by superposition with the yield potential of the tessellated stresses, which is greater. Whatever be the rate of transformation and the degree of redistribution of both stress systems, the sign of the final tessellated stresses cannot be changed by the superposition of the residual body-stresses.

If the transformation proceeds gradually over subsequent layers towards the core of the body, a different system of very high body-stresses develops, with tension in the outer shell and compression in the core of the body, according to Maurer,[1] who, however, does not consider tessellated stresses. For different reasons, neither of these body-stresses seems to be responsible for the retention of austenite.

Since numerous martensite crystals issue from one single austenite grain, it may be assumed that the enveloping surface of the bulk of martensite crystals will suffer a certain tessellated distortion, setting up, in combination with the surroundings of the enveloping surface, a special system of tessellated stresses. The individual masses of the finally retained austenite are minute, and have such a very high ratio of surface to volume that the energy necessary for the initiation of that secondary tessellated process may be considered to become greater than can be accounted for by the united potentialities for transformation. The resistance against tessellated distortion of the surface may be an essential factor in the explanation of some metallurgical phenomena other than the retention of austenite.

The urge towards a change of phase due to excessive free energy and tessellated stresses increases with a fall in the temperature of transformation, *i.e.*, with increasing rate of quenching, and undercooling. The transformation is further accelerated by the more concentrated application of the kinetic energy of the nascent martensite to the actually retained austenite. The size of a single mass of finally retained austenite probably therefore becomes reduced.

If, however, the process of transformation is accelerated, there may not be sufficient time for the process to be so directed that a minimum number of minute masses of austenite remains untransformed. These opposing efforts seem to explain why there is a certain medium degree of undercooling, and corresponding medium rate of transformation (with plain carbon steel), at which there is a maximum percentage of austenite retained.

While rapid cooling may considerably upset the regularity of the three-stage process of tessellation, the order of magnitude and the sign of the final tessellated stresses cannot be affected. Increased rate of transformation causes the development of an increased apparent yield resistance of the materials, and prematurely interrupts the yield process of austenite, as this ceases when the austenite

[1] E. Maurer, *Stahl und Eisen*, 1927, vol. 47, pp. 1323–1327.

is transformed; thus, the possible degree of yield and the amount of redistribution of stresses are reduced.

Martensite which has passed through its nascent state is brittle; the reduced tension on it has been calculated, and is shown in Figs. 5 to 7, without the reduction by the unknown factor Z : 487,290. Whatever may be the true values of $F_{red\ oj}$ and $F_{red, os}$, they are the high internal stresses which have been very much referred to by metallurgists [1] in a somewhat nebulous way, in an attempt to explain, among other phenomena, the minute cracks occasionally discovered in etched martensite. Their effectiveness in forming cracks is greatly enhanced by the suddenness with which they arise.

Large cracks in martensite are obviously due to body-stresses, their nuclei being tessellated minute cracks. This is readily understood if large cracks occur during hardening. If they occur after a more or less extended period of rest after hardening, in the absence of corrosion, it may be assumed that some retained austenite is spontaneously transformed to α-martensite, or some crystals of α-martensite are transformed to β-martensite, thus providing an impulse to the formation of large cracks otherwise puzzling.

The transformation of α- to β-martensite by tempering at about 100° C. is accompanied by a tessellated-stress system having a strain potential of 0·00944 and a yield potential of 404,570 lb. per sq. in. so that, contrary to the case of transformation of austenite to α-martensite, the β-martensite is subjected to tessellated tension and the retained austenite to compression by this part of the process. The result of the superposition of these two opposing systems of tessellated stresses depends on the unknown degree of yield and redistribution of stresses occurring during both processes, so the discussion must be very reserved. The final tessellated stress on the retained austenite ought to be either compressive or, if tensile, of a lesser magnitude than before tempering at 100° C., thus removing the danger of crack formation initiated by spontaneous transformation after certain periods of rest, as assumed above. If the heating to 100° C. is carried out very slowly, and therefore uniformly over the whole mass, previously developed body-stresses may be more or less reduced, owing to the temporary plasticity of the nascent β-martensite and its low rate of formation.

When α- or β-martensite is cooling to room temperature, after hardening or tempering, a further system of tessellated stresses develops, owing to the coefficient of thermal expansion of austenite being greater than that of martensite. (Neither of the latter has yet been determined for plain carbon steel of 0·9–1·2% carbon content.) This system superimposes some tension in the retained austenite, and compression in the martensite, on the tessellated stresses previously developed. Since the specific volumes of austenite, and α- and β-martensite on which the foregoing calculations were based refer to room temperature, the stresses calculated

[1] Epstein, *loc. cit.*, pp. 263–264.

for phase transformation include also those due to superposition of the cooling stresses from the temperature of transformation down to room temperature.

For tessellated stresses due to steel hardening, the characteristic factor of relaxation is, at surface intersection, of course 0·7.

Miscellaneous Problems.

Compact slag inclusions in iron and steel, *i.e.*, not including such as are formed by the oxidation of the surface of blow-holes by oxygen separated during solidification, can be represented as core components of either a spherical or a cylindrical system of tessellation. As the physical constants of slag are not known, those of glass will be considered. In order to reduce the danger of serious errors, the greatest coefficient of thermal expansion and the least modulus of elasticity recorded for glass are used in the calculation of tessellated stresses around minute slag inclusions, the volume of which is considered to be equal to 0, *i.e.*, $a_s = 8 \times 10^{-6}$ and $E_s = 8 \times 10^6$ lb. per sq. in. The ooly statement for Poisson's ratio of glass was found to be $m = 4$; this will be used for slag.

Row 1 of Table II. shows the stresses developed in spherical or cylindrical tessellation of slag with iron, due to a temperature drop of 680° C. For steel the figures are to be reduced by a factor $\dfrac{a - 8 \times 10^{-6}}{(14{\cdot}98 - 8) \times 10^{-6}}$, where a denotes the coefficient of thermal expansion of the steel under consideration. In both cases the slag is under compression, so that no reduced tension develops in it at all, and the slag is not affected by the stresses. The yield potential, $f_{red,oj}$, acting on the ferrite is so high that local yield and redistribution of stresses seem to be inevitable.

When steel is hardened, the slag cools down in austenite. If it be arbitrarily assumed that the average coefficient of thermal expansion of austenite with 0·9% of carbon is 17×10^{-6} for the range 20–700° C., then the tessellated stresses developed on cooling through this range are as shown in row 2 of Table II. The drop of 680° C. is certainly greater than is normal in practice. Its consideration facilitates comparisons with other calculations in this paper. It does not matter what fraction of these stresses really develops; there is no doubt that the inclusions cause high tessellated tension on the surrounding austenite, and prove to be most efficient nuclei for the transformation of austenite to any other phase, because this is always accompanied by volume expansion. If transformation to α-martensite follows the temperature drop, the stresses of row 3 result. In spite of many uncertainties regarding physical constants, yield and relaxation, it is apparent that the slag is subjected to such a tension, $F_{red,i}$, that it may crack and/or lose its bond with the matrix. The reduced tension, $F_{red,oj}$, acting on the martensite matrix seems to be less than is necessary for crack

TABLE II.—*Tessellated Stresses, lb. per sq. in., around Minute Inclusions of Slag.*

Row.	Description.	Spherical Inclusions.					Cylindrical Inclusions.					
		p.	$f_{t,oj}$.	$f_{red,oj}$.	$F_{red,t}$.	$F_{red,oj}$.	p.	$f_{t,oj}$.	$f_{red,oj}$.	$f_{a,t}$.	$F_{red,t}$.	$F_{red,oj}$.
1	Slag in ferrite, temp. drop by 680° C.	−56,390	+28,200	84,590	−28,200	...	−48,850	+48,850	97,700	−62,400	−21,040	...
2	Slag in austenite of 0·9% carbon, temp. drop by 680° C.	−72,710	+36,360	109,070	−36,360	...	−62,980	+62,980	125,970	−80,450	−27,130	...
3	Matrix subsequently transformed into α-martensite	+60,850	−30,430	91,280	+30,430	+79,110	+52,710	−52,710	105,420	+67,330	+40,970	+68,530
4	Matrix finally transformed into β-martensite	−51,260	+25,630	76,890	−25,630	+33,320	−44,400	+44,400	88,800	−56,720	−19,120	+57,720

formation, probably even $f_{red,oj}$ is not high enough to cause the nascent martensite to yield. If its bond with the matrix does not fail, slag is also an efficient nucleus for the transformation from α- to β-martensite, which reinstates compression in the slag and tension in the metallic matrix, as shown in row 4.

Austenite frequently contains minute spheres of ferrite or cementite that either have not gone into solution during heating or have separated after the heating was stopped. For these minute spheres v_i can be put equal to 0 in the equations for compound spheres. Table III. shows the tessellated stresses around such nuclei. Minute

TABLE III.—*Tessellated Stresses, lb. per sq. in., around Minute Inclusions of Ferrite or Cementite.*

Row.	Description.	Spherical Inclusions.				
		p.	$f_{t,oj}$.	$f_{red,oj}$.	$F'_{red,i}$.	$F_{red,oj}$.
1	Minute ferrite in austenite, temp. drop by 680° C.	− 39,250	+ 19,120	58,370	...	...
2	Matrix subsequently transformed into α-martensite	+281,950	−140,980	422,930	...	+366,540
3	Matrix finally transformed into β-martensite	+ 12,340	− 6,170	18,510	...	+ 16,040
4	Minute cementite in austenite, temp. drop by 680° C.	− 94,810	+ 47,400	142,210	−37,920	...
5	Matrix subsequently transformed into α-martensite	+226,390	−113,190	339,580	+90,560	+294,300
6	Matrix finally transformed into β-martensite	− 43,220	+ 21,610	64,830	−17,290	+ 28,090

spheres of cementite seem to be very vigorous agents of transformation. Since correction for the plastic yield of nascent martensite cannot be made, the figures of Table III. are once more of qualitative value only. The minute spheres of ferrite and cementite behave in connection with the transformation of austenite to α- or β-martensite just as slag does. The probability of tessellated stresses breaking up the bond between α-martensite and minute nuclei of cementite is less than in the case of slag. It is, however, noteworthy that the loss of blocks of cementite during the preparation of micro-test-specimens sometimes causes trouble, though like difficulties with slag are occasionally much greater.

The characteristic factor of stress relaxation at surface intersections is 0·71 in connection with slag, and 0·70 in other cases.

Tessellated stresses of structural type have a considerable influence on many properties of, and phenomena observed with, solids. Tessellated stresses and minute plastic strains in the interior of a body seem to be connected with crack formation, to provide the nuclear effect for transformation and to promote recrystallisation and precipitation. The tessellated stresses at a free surface require further attention, since the relaxation on the whole is only moderate, and they must exert some influence on corrosion,

especially the grain-boundary type, and on fatigue. As to the latter, it has been extremely puzzling that the most carefully made surface of best purity steel proved deficient even in the absence of corrosion. This is revealed by testing in alternating tension and compression steels suitable for either case-hardening or nitriding, with their surface layer in the unhardened condition and in the hardened condition. Though tessellated stresses are reduced in intersected units, it may be assumed that the presence of these intersected units would have the effect of a detrimental singularity, and be responsible for this phenomenon.

Though the only questions discussed have been concerned with iron and steel, tessellated stresses appear to have a great influence on nearly all solids. Related problems seem to be certain effects of grain-boundary segregation in otherwise homogeneous metals, the peculiar weakness against selective corrosion of $\alpha + \beta$ brass, the influence of small portions of heterogeneous components in austenitic steel or in different aluminium-base metals, the whole process of growth of cast iron and even that of tin pest. The position is similar with regard to many phenomena of non-metallic solids, *e.g.*, that of the sulphur-unsoundness of concrete, the effect of repeated changes of temperature on ceramics, and others.

Hydrogen in Steel.

If flake formation takes place during cooling at a possibly small but still effective rate, it is to be assumed that the actual pressure potential p of the separating molecular hydrogen is uniformly applied to all voids, the volume of which is negligible, *i.e.*, $y = 0$. The pressure potential, *e.g.*, in a steel with carbon 0·01%, nickel 3·1% and chromium 2·6%, has values of $p = -640, -5{,}430, -62{,}000$ and $-570{,}000$ lb. per sq. in. for weight percentages of hydrogen of 0·0001%, 0·0003%, 0·001% and 0·003%, respectively, all at 200° C., at about which temperature the formation of flakes occurs.[1] Though the bulk percentage of hydrogen in steel of standard quality [2] is usually less than 0·001%, it is probable that hydrogen has a much greater local concentration in the dendrites,[1] and the correct calculation should consider the pressure potential due to that increased weight percentage.

From equation (7), $f_{t,oj} = -\frac{1}{2}p$, $f_{red,oj} = \frac{3}{2}p$, and $F_{red,oj} = -0{\cdot}65p$, which are all distinctly different from what has previously been considered, *viz.*, that the stresses in the surrounding metal are equal to the pressure potential p.[1] The above stresses may be substantially raised by stress concentration at irregularities in the shape of the voids and/or by tessellated stresses due to reasons other than gas separation.

The formation of typical flakes is apparently an explosion-like

[1] H. Bennek, H. Schenck and H. Müller, *Stahl und Eisen*, 1935, vol. 55, pp. 321–328.

[2] Epstein, *loc. cit.*, p. 8.

process, since the cracks are accurately flat and circular; their size is incomparably greater than that of the greatest possible voids, and, while their position is confined to segregated portions of the body, the orientation of the plane of the cracks is not distinctly controlled by that of the dendrites. It is not clear why even a great internal stress should cause such "explosions" to take place, since the metal around the voids is ductile and would be expected to yield and/or to open small irregular cracks, perhaps even submicroscopic ones, thus reducing the pressure in the voids and also relieving its own stresses. The assumption that martensite transformation may be an essential factor in flake formation has often been made, but rejected because of the failure to obtain visual evidence of the process.

Since flakes occur mostly in segregated portions of steel, they may be explained by assuming that small regions of the austenite are so enriched in certain alloying elements that they do not undergo the pearlite transformation with the bulk of the body at relatively high temperature, even with slow cooling, but that their transformation is delayed until the temperature falls appreciably. They may then undergo either of two possible types of transformation, *viz.*, to troostite or to martensite. It should not be expected that either of these would be revealed by bulk observations of the body during cooling, since the mass concerned would be too small. Furthermore, there are certain reasons why even microscopic observation may not be able to disclose with certainty such delayed transformations of small portions of the steel. It seems, therefore, that the question whether the transformation to martensite is an essential factor in flake formation cannot be decided on the basis of existing data.

If delayed transformations are to be considered it is better to deal with plain carbon steel, as, for this, the requisite physical constants are better known than for certain alloy steels which are ill-famed for flake formation. This is unfortunate, since plain carbon steel with moderate carbon and manganese percentages would not develop really typical flakes. Minute spheres of austenite of 0·9% carbon in a pearlitic matrix of 0·4% carbon are subjected, on cooling from 700° to 200° C., to a yield potential of 47,000 lb. per sq. in., on which is superimposed either 123,000 or 493,000 lb. per sq. in. due to transformation to troostite or to martensite, respectively, at 200° C. The resulting nascent stress conditions are respectively:

$$\begin{aligned} f_{red,\,oj} &= 76{,}200 \text{ or } 446{,}000 \text{ lb. per sq. in.} \\ p &= -\,50{,}800 \text{ or } -\,297{,}400 \text{ lb. per sq. in.} \\ f_{t,oj} &= +\,25{,}400 \text{ or } +\,148{,}700 \text{ lb. per sq. in.} \\ F_{red,\,oj} &= +\,33{,}000 \text{ or } +\,193{,}300 \text{ lb. per sq. in.} \end{aligned}$$

The values of $F_{red,\,oj}$ are shown, since the material seems to crack in a brittle manner, owing to its being prestressed by tessellated stresses due to hydrogen and to cooling. The brittle manner of cracking may even suggest consideration as to whether the transformation stresses should be superimposed with their simple or double values.

The conclusion is that hydrogen pressure and the stored energy of tessellated stresses due to cooling account for the energy required for the "explosion," and it is possible that tessellated stresses due to the phase transformation of small undercooled masses are the "detonators." Body-stresses, which were frequently considered in the past, are certainly inoperative in the case under consideration, because of the slow cooling.

If the cooling is so slow that flakes no longer develop, it is to be assumed, as usual, that much of the hydrogen vanishes by diffusion and the remainder develops only moderate pressure in the voids. An alternative or possibly an additional reason is that the transformation of minute masses of undercooled austenite takes place at temperatures—higher than those with slightly quicker cooling—at which the pressure potential of hydrogen is sufficiently reduced, and the matrix possibly is less liable to a brittle fracture by the impact of the transformation.

Flakes also develop under conditions which are different from those discussed above. Tessellated stresses due to hydrogen are always a primary agent, and it is open to discussion whether a selective phase transformation of small masses actually initiates the process. If flakes are formed during quick cooling or heating, body-stresses also contribute to this effect. Flake-like cracks which are opened by external forces in hydrogen-bearing steel are of course, connected only with tessellated stresses due to gas pressure, not with those due to transformation in general.

Careless pickling causes atomic hydrogen to penetrate into the surface layer, whereupon it combines to molecules in voids, thus developing high internal pressure. On investigating micro-test-specimens, the metallurgist may observe a varying number of discontinuous hair-cracks near the surface. This condition may be cured by annealing at temperatures suitable for complete stress relief, so that it would not be affected by subsequent brazing operations. Otherwise, the latter may readily give rise to a honeycomb-like infiltration along the grain boundaries in the surface layer.

It is obvious, for well-established reasons, that the surface layer is subjected to body-tension during the infiltration of the brazing alloy. This body-tension is, no doubt, a consequence of the tessellated stresses due to hydrogen pressure in the voids of the surface layer. Since the resistance against outward strain at right angles to the surface is small, the voids are readily enlarged by elastic and plastic distortion and by the formation of hair-cracks in the surrounding metal, so that their volume fraction relative to the total volume of the surface layer is no longer very small. The body tensile strain of this surface layer, *i.e.*, $\frac{m-1}{mE} f_{t,os}$, in accordance with equation (7), cannot fully develop, owing to the resistance of the core portion of the specimen. Body-stresses are set up, therefore, in the surface layer and core, with their bulk values inversely

proportional to the respective volume fractions. In order to explain the apparent existence of body-tension in the surface layer during brazing, it is to be assumed that the body-compression of the surface layer, which is primarily caused by the high internal pressure, exceeds the elastic limit of the material, so that when the hydrogen is eventually discharged from the voids the surface layer shrinks and becomes subjected to body-tension. It is not possible to find out, by analysis of existing reports on brazing cracks, when exactly the different phases of this process develop in the surface layer.

Concluding Remarks.

The discussion of some questions regarding iron and steel has revealed that tessellated stresses have, in general, a fundamental influence on the properties of solids. The present limits to, or lack of, knowledge of certain physical constants and technological figures make quantitative inferences difficult. Fairly certain qualitative conclusions may, however, be drawn.

The tessellated stresses studied have been almost exclusively of the structural type; the stresses due to crystal anisotropy have not been superimposed. Since only qualitative conclusions were attempted, it was apparent that nothing could be achieved by such superposition.

It should be emphasised, once more, that numerous details connected with the problems discussed, and many other problems relative to solids, including the possible tessellated stresses in individual crystals, seem to be worthy of future investigation.

Acknowledgments.

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GRAPHITISATION OF STEEL INFLUENCED BY TESSELLATED STRESSES.[1]

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(Figs. 1 to 4 = Plate II.)

SUMMARY.

A study of the tessellated stresses set up on cooling carbon steel supports the theory that the graphite is first precipitated from the ferrite matrix and is not a product of the direct decomposition of cementite.

SOME twenty years ago Professor Neill Greenwood carried out extensive investigations on the graphitisation of steel wire and discussed the results in 1921 in an unpublished manuscript as part of his thesis for the D.Sc. degree at Manchester University. When Professor Greenwood was informed of the inferences which the present author had drawn from a study of tessellated stresses,[2] he suggested a further study of his above-mentioned manuscript.

The author is much indebted to Professor Greenwood for permission to publish some of the findings and illustrations of this manuscript, as they give an impressive demonstration of the influence of tessellated stress on metallurgical processes.

Professor Greenwood investigated the possible causes of the formation of graphite in steel wires containing 1·0–1·1% of carbon, 0·45–0·65% of manganese, 0·1–0·2% of silicon and less than 0·04% of both sulphur and phosphorus. The procedure adopted was as follows: Suitable ingots were hot-rolled to 5-gauge rods; the latter were annealed at 700° C., cleaned, limed, blued and drawn to $6\frac{1}{2}$-, 8-, $9\frac{1}{2}$-, 11-, $12\frac{1}{2}$- and 14-gauge, the annealing, cleaning, liming and blueing being done after each draw. The annealing was carried out in pots; 6 hr. were required to reach the annealing temperature, which varied between 625° and 700° C., after the different drawing operations; then followed soaking for 6 hr., slow cooling in the furnace to 550° or 600° C. over a period of 10 hr. and final cooling to room temperature over a period of 24 hr. in an enclosed pit.

Under such conditions the first signs of carbon precipitation were found in wires of a suitable inherent nature on annealing after drawing to $9\frac{1}{2}$-gauge. Fig. 1 illustrates the microstructure of the

[1] Received January 1, 1943.

[2] "Tessellated Stresses.—Part I.," *Journal of The Iron and Steel Institute*, 1943, No. I., pp. 173 P–199 P (this Journal).

$9\frac{1}{2}$-gauge wire before annealing, Fig. 2 that after annealing, the latter showing the first traces of precipitated graphite,

> ". . . and it is interesting to note that although it [the graphite] appears during annealing it occurs in elongated streaks. . . .
>
> "The fact that, on its first appearance, the temper carbon is elongated suggests that it is deposited from a phase which has been drawn out in the earlier mechanical treatment. Such a phase might be a solid solution . . . which holds carbon along with it. . . . It is quite certain that it is not the cementite granuli which first decompose but the ferrite surrounding them. In fact, it is frequently found that the nodules of cementite occur adjoining or even inside the decomposed masses. Such can readily be seen in Fig. 3, which shows the same coil after two more drawings and annealings. The idea of ferrite holding carbon in solution is not new—and in fact it is essential in order to explain the spheroidisation of steel (none of which passed 700° C. after the hot-rolling). If there is no solubility of carbon (or carbide) in iron below 725° C. it is difficult to imagine how the exceedingly minute spheres of cementite in the original sorbite can have become the large spheres of Fig. 1. The particles must have coalesced, and unless they have been drawn bodily to some large particle, they must have moved by diffusion, which involves solution.
>
> "We are forced to the conclusion, then, that ferrite in the neighbourhood of cementite granules is capable of holding appreciable quantities of carbon in solution at temperatures of 625–700° C., and under certain conditions this carbon is precipitated, probably during cooling."

Fig. 4 shows the distribution of the carbon centres after annealing the $12\frac{1}{2}$-gauge wire.

It is remarkable with what clarity Professor Greenwood's photomicrographs reveal the peculiar start of the precipitation of temper carbon. Equally remarkable was his unfaltering explanation of its source, as it might have met with fierce discussion had it been published twenty years ago. Even his assumption that the precipitation occurs probably during cooling is very noteworthy.

The actual steel contained 1·08% of carbon. Because of the difference in coefficients of expansion of cementite and ferrite, tessellated stresses are set up in the system on cooling from the annealing temperature. With the same notation as that used in "Tessellated Stresses.—Part I." (*loc. cit.*), the cementite spherules are subjected to a radial stress p. The stresses in the ferrite at the surface bounding the cementite are a radial stress p and two equal tangential stresses $f_{t.oj}$; midway between two adjacent spherules the radial stress is zero and the two equal tangential stresses are f_{tos}. The rate of change of each of these stresses with respect to

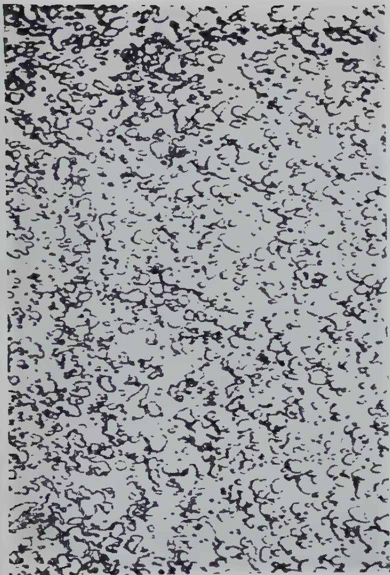

FIG. 1.—9½-Gauge Wire before Annealing. × 800.

FIG. 2.—9½-Gauge Wire after Annealing, showing first traces of precipitated graphite. × 800.

FIG. 3.—The Same Wire after two more drawings and annealings. × 800.

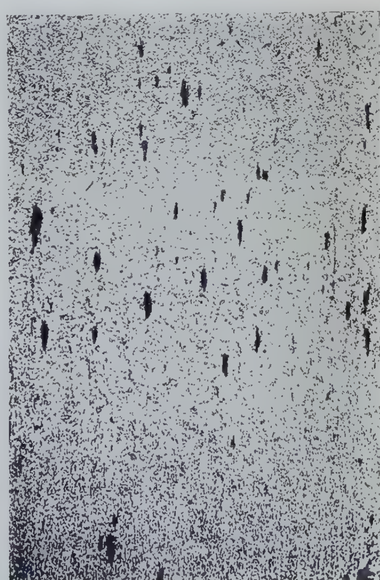

FIG. 4.—Distribution of the Carbon Centres in the 12½-gauge wire after annealing. × 100.

(Micrographs reduced to four-fifths linear in reproduction.)

[*László.*

[*To face p.* 202 P.

temperature can be found from equation (2a) (*loc. cit.*). By using the values 30×10^6 lb. per sq. in. for E, and $\frac{10}{3}$ for m, which are practically constant at ambient temperatures, it is found that the changes of these stresses caused by a 1° C. fall of temperature near atmospheric temperature are : $\delta p = -67{\cdot}25$ lb. per sq. in., *i.e.*, the radial compressive stress is increased by 67·25 lb. per sq. in.; $\delta f_{t,oj} = 53{\cdot}6$ lb. per sq. in.; and $\delta f_{t,os} = 19{\cdot}98$ lb. per sq. in., the latter two, of course, being increases of tensile stress. The values of E and m, however, vary with temperature, and at higher temperatures may be greatly different from those at room temperature. This would involve variations of dp/dT with temperature, and to determine the value of p on cooling over a range of temperature dp/dT would have to be integrated over the range of cooling concerned, say, from T_1 to T_2. This theoretical pressure p may possibly be reduced by gradual plastic deformation which is some function of the momentary value of the true pressure P and temperature T, and the rate of cooling dT/dt, so that the actual pressure P will be given by an equation of the form :

$$P(T_2) = \int_{T_1}^{T_2} \frac{dp}{dT} \,.\, dT - \int_{T_1}^{T_2} R\left(P(T), T, \frac{dT}{dt}\right) . \, dT.$$

The pressure P is limited in the following way : The yield potential, $f_{t,oj} - P$, cannot develop fully if at any time it exceeds the creep resistance of the material corresponding to the three-dimensional stress conditions, the temperature and the rate of cooling at that time, *i.e.*, for a steel containing 1·08% of carbon :

$$\left| f_{t,\,oj} - P \right| = \left| - P \,.\, \frac{1 + 2v_1}{2v_0} - P \right| = 1{\cdot}797P \not> \text{actual creep resistance.}$$

Since the stress distribution in the ferrite matrix will be equalised to some extent, $f_{t,oj}$ will be less than $-\dfrac{1 + 2v_1}{2v_0} \,.\, P$ and P at some time during cooling numerically greater than 1/1·797 of the actual creep resistance at that time.

The essential finding is that during cooling the cementite spheres are subjected to a hydrostatic compression P, and the ferrite matrix to tensile stresses. Since carbon precipitation is accompanied by a comparatively large increase of volume, it is obvious that during cooling carbon precipitation out of the solid solution of cementite in ferrite should be greatly facilitated by tessellated stresses. This is in exact accord with Professor Greenwood's observations, and also with his assumption that the carbon precipitation from ferrite occurs during cooling. It is, furthermore, questionable whether cementite spheres would decompose at all during cooling.

In order to support his metallographical finding, Professor Greenwood also made some investigations into the solubility of

carbon in ferrite at temperatures below A_1. Though that investigation was not directly related to questions of tessellated stresses, it may be of interest to mention its results. Professor Greenwood, in 1921, heated wire samples of the quality under consideration at temperatures of 500°, 550°, 600°, 650° and 700° C., for 2 hr., quenched them and compared their electrical resistance with that of wire cooled at a moderate rate. He found " roughly " that ferrite takes at least 0·02% of carbon into solid solution at 700° C. and that the solubility practically vanishes at 500° C.

In order to prevent any misinterpretation, it should be mentioned that the rôle of tessellated stresses in the initiation of carbon precipitation is only of a mechanical character. Professor Greenwood devoted himself in those investigations exclusively to the study of metallurgical factors which were responsible for the readiness of certain melts of steel of the quality under consideration to precipitate carbon under suitable circumstances.

CORRESPONDENCE.

Dr. A. L. Norbury (Ministry of Supply, Birmingham) wrote : The elongated form of the graphite and its general distribution in Figs. 2 to 4 suggest that it had been deposited on rolled-out streaks of manganese sulphide and other non-metallic inclusions, rather than on the carbide particles. Deposition of graphite on manganese sulphide and on other inclusions is well established in the case of blackheart and whiteheart malleable.

In the same way graphite precipitation from molten grey cast iron is apparently facilitated by the presence in the melt of solid non-metallic inclusions.[1]

The above effects do not appear to be dependent on the crystal structures of the non-metallic inclusions and consequently seem to be due to some boundary effect such as " stresses " in the outside layers of atoms of the iron lattice, through the outside atoms being unable to register with, and link up with, the atoms in the non-metallic inclusion.

The idea that " stressing " of the iron lattice favours graphitisation has also been put forward to explain the observation that the graphitising effects of elements in solid solution in cast iron increase as the solute atoms and iron atoms differ in size.[2]

It is regretted that the author's reply has not been received at the time of going to press.

[1] A. L. Norbury and E. Morgan, *Journal of The Iron and Steel Institute*, 1936, No. II., pp. 327 P–358 P.

[2] A. L. Norbury, *Journal of The Iron and Steel Institute*, 1939, No. II., p. 175 P.

THE CALIBRATION OF THE PLATINUM/13%-RHODIUM–PLATINUM THERMOCOUPLE OVER THE LIQUID STEEL TEMPERATURE RANGE.*

BY C. R. BARBER, B.Sc. (NATIONAL PHYSICAL LABORATORY, TEDDINGTON, MIDDLESEX).

(Fig. 2 = Plate III.)

Paper No. 17/1942 *of the Committee on the Heterogeneity of Steel Ingots (submitted by the Liquid Steel Temperature Sub-Committee).*

SUMMARY.

The e.m.f.'s of eight platinum/13%-rhodium–platinum thermocouples have been measured at the melting points of gold, palladium and platinum by the wire method. On the basis of these determinations and the existing e.m.f./temperature relation up to 1550° C., a reference table for the platinum/13%-rhodium–platinum thermocouple covering the range 1400° to 1770° C. has been computed. It is estimated that the accuracy of the calibration in terms of the International Temperature Scale is ± 3° C. up to 1600° C. and ± 5° C. beyond this temperature.

INTRODUCTION.

THE development of the quick-immersion technique for the use of platinum thermocouples for the measurement of the temperature of molten steel has now reached the stage when the method is being usefully employed for temperature control in steelmaking. In the preliminary experiments the absolute accuracy of calibration of the thermocouples was not of importance, but now that the method appears to be well-established an accurate calibration is clearly desirable. Hitherto, platinum couples have not been used extensively above about 1550° C. on account of the relatively rapid rate of deterioration of the couple wires at such high temperatures, and thus there has been little demand for a calibration extending beyond this temperature. The present work has therefore been undertaken in order to provide e.m.f./temperature reference tables for the platinum/13%-rhodium–platinum thermocouple over the range 1400° to 1770° C.

The temperature scale used in arriving at the calibration data should be the International Temperature Scale, which is defined for temperatures above 1063° C. by the melting point of gold (1063° C.) and a value of 1·432 cm.-degrees for the constant C_2 in the Wien law of radiation, the disappearing-filament optical pyrometer being the instrument normally used for realising the scale. Strictly, therefore,

* Received August 4, 1942.

the calibration of a thermocouple over the range of temperature 1400–1770° C. involves a point-to-point comparison of the optical pyrometer and thermocouple, which at high temperatures is a difficult and lengthy process. As an alternative, however, indirect reference may be made to the International Temperature Scale by calibrating the thermocouples at fixed points which have already been determined precisely by means of the optical pyrometer. On the basis, therefore, of the melting points of gold (1063° C.), palladium (1555° C.) and platinum (1773° C.) and the existing data of the thermocouple scale below 1550° C., it is considered that a calibration of the thermocouple from 1400° to 1770° C. may be drawn up which will reproduce the International Temperature Scale with sufficient accuracy for present needs. This method of calibration is the one here adopted, and the details of the apparatus and measurements are given below.

Method and Apparatus.*

The well-known wire method of calibration was used at all three fixed points. Although this method is sometimes considered not to yield such high accuracy as the ingot method, it can with certain precautions show a surprisingly high precision, while it has the advantage of requiring only simple apparatus and a very small quantity of melting-point material. According to the method, a short length of the melting-point metal is joined between the ends of the two wires of the thermocouple under calibration (test couple) and placed, together with another couple (control couple), in an electrically heated furnace, the temperature of which is slowly raised, alternate readings of the e.m.f. of the couples being taken on a potentiometer. When the melting point of the metal is reached, the e.m.f. of the control couple continues to rise, while that of the test couple remains steady for a minute or two and then drops to zero on the breaking of the circuit due to the fusion of the metal forming the junction. The steady e.m.f. value immediately before the rupture is taken to be the e.m.f. of the couple at the melting point of the metal.

The measurements at the gold point are quite straightforward, but those at the higher temperatures may be subject to error mainly on account of the poor electrical insulating properties at high temperatures of the refractory materials of the furnace tube and thermocouple insulators. Thus, considerable error may arise by leakage from the furnace winding to the thermocouple circuit, should the wires be allowed to make contact with the hot furnace wall. In addition, an electrolytic effect appears to exist between thermocouple wires in contact with a refractory insulator at high tempera-

* A fuller description of the apparatus and details of the technique to be followed in making the measurements are given in the pamphlet "The Technique of Calibrating Platinum Thermocouples for Use in Liquid Steel." London, 1942: H.M. Stationery Office.

ture, revealing itself in the experiment by causing a high e.m.f., sometimes of the order of several millivolts, to be developed when the junction breaks. The following general conclusions were drawn from experiments conducted on the measurement of this e.m.f. and the circuit resistance under various conditions: That the effect exists both with A.C. and D.C. heating of the furnace, although smaller with the former; that reversing the direction of flow of the furnace current reverses the effect; that the resulting error is not likely to exceed a few microvolts. The phenomenon, with particular reference to the palladium point, has been discussed at some length by Fairchild, Hoover and Peters.(1) In the present measurements inaccuracies on this account and by reason of leakage from the furnace winding were avoided by arranging that the insulators covering the thermocouple wires touched neither each other nor the furnace walls.

Eight thermocouples were calibrated, four being lent for the purpose by Messrs. Johnson Matthey & Co., Ltd., and four by The Sheffield Smelting Co., Ltd. The couple wires, which were 0·5 mm. in dia., were annealed by passing a current of about 13·5 amp. through them for about one minute. Each wire was threaded into a recrystallised alumina tube, 0·7 mm. in bore, of 0·5 mm. wall-thickness and 150 mm. long, about 25 mm. of the wire being left bare at the hot-junction end. The couples were mounted in pairs in clamps consisting of brass blocks having four parallel holes, into which the insulators were threaded and clamped at their ends by set-screws, so that they were held parallel to but not touching each other. A cross-section of this clamping-block is shown in Fig. 1, together with a diagram of the furnace assembly. Two furnaces were used, one for the gold and palladium points and the other for the platinum points, each having a recrystallised alumina central tube, 12 mm. in bore, of 2·7 mm. wall-thickness and 300 mm. long. The first-mentioned furnace had a spiral winding of platinum/10%-rhodium foil, 12·5 mm. wide and 0·025 mm. thick, covering the whole length of the tube, a space of 1–2 mm. being left between the turns. The leads to the furnace winding each consisted of four strands of platinum wire, 0·5 mm. in dia., welded to the ends of the foil. The platinum-point furnace had a winding of pure rhodium foil, 6·3 mm. wide and 0·075 mm. thick, with similar spacing of turns but covering only half the length of the tube, the long tube being used because a shorter one was not immediately available. As explained later, the greater length of the furnace winding employed for the gold and palladium points was on account of the need for greater temperature uniformity at these points than at the platinum point. The central furnace tube in each case was packed in alumina powder contained within a silica tube, which was in turn packed in Sil-o-cel powder. The outer diameter of the furnace case was about 200 mm. The approximate rating of the furnaces at each of the points was 10 amp., 15 V. at the gold point, 12 amp., 21 V. at

the palladium point and 16 amp., 17 V. at the platinum point. The furnaces were operated in the vertical position, the pair of test couples being lowered into them from above and adjusted so that the insulators were not in contact with the furnace wall and the junctions were at the hottest part of the furnace. In order to be able to see into the furnace when making this adjustment, the metal block of the clamp had been cut away as shown in Fig. 1. An alumina disc was placed just below the test-couple junctions to

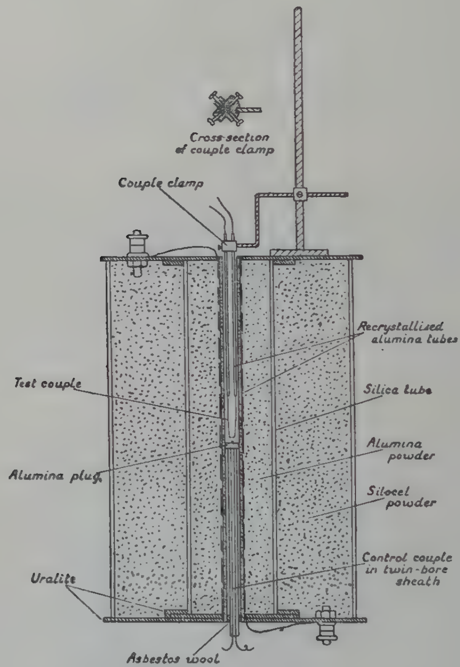

FIG. 1.—Furnace Assembly for Calibrating Thermocouples by the Wire Method.

reduce convection and radiation losses and thus temperature gradients in the neighbourhood of the junctions. The control couple, mounted in a twin-bore insulator, was inserted into the furnace from below and placed with its junction adjacent to the disc which was supported by the twin-bore insulator. In the platinum-point experiments the control-couple junction was placed in a cooler part of the furnace, so that it remained intact when the test couples reached the melting point. The rate of rise of the furnace temperature during the observations was adjusted to be of the order of 0·5° C. per min. for the gold point and 1° C. for the palladium and platinum

(*a*) Gold Point, before melt. (*b*) Platinum Point, before melt. (*c*) Platinum Point, after melt.

FIG. 2.—Thermocouple Junctions.

[*Barber*.

[*To face p.* 208 P.

points. In order to be able to maintain this rate steady a reasonably constant voltage electrical supply was necessary. Since the furnaces used were small in size and so of low heat capacity, the mains supply was not sufficiently steady and it was found convenient to use a 50-V. battery. Larger furnaces could be operated on a less steady supply, but speed of adjustment of the temperature would be sacrificed on account of the greater thermal lag involved.

The gold and palladium wires were fused on to the ends of the thermocouple wires. Each junction was made by melting back the end of the gold (or palladium) wire in an oxy-coal-gas flame, so that the bead thus formed embraced the end of the thermocouple wire without the latter being melted. In this way it was possible to avoid extensive alloying of the two metals and the consequent errors due to contamination both of the melting-point metal and of the thermocouple wires. When the wire had been so joined it was about 3 mm. long. In Fig. 2(*a*) a photograph of a gold-wire junction clearly illustrates that the ends of the couple wires have not been fused.

The experiment at the melting point of platinum is the same in principle, but no additional wire is here required since the melting-point material forms one arm of the thermocouple. The thermocouple wires were fused together at the junction, and the position of the couple was adjusted in the furnace until the maximum e.m.f. reading was given, thus ensuring that the junction was at the hottest part of the furnace and hence that fusion would commence at the junction. It was found that by arranging the bare couple wires projecting from the insulators to be close together (about 2 mm. apart) the platinum wire, after fusion at the junction, was still held in contact with the platinum-rhodium wire by surface tension of the bead, which moved up the alloy wire as the platinum arm melted back. The photographs in Figs. 2, (*b*) and (*c*), illustrate the appearance of the junction before and after the experiment. Occasionally small irregularities on the surface of the alloy wire over which the platinum bead had passed seemed to indicate that small quantities of platinum had been left behind, but, generally, the surface of the platinum-rhodium wire had retained its original polished appearance. This evidence, combined with the fact that the e.m.f. of the couple remained steady to within two or three microvolts while the platinum arm was melting back some 1·5 cm., leaves little doubt that the melting point given was that of the pure platinum. In connection with this point Todd [2] has shown that two platinum wires twisted together melted at the same time as a platinum wire twisted with a platinum-rhodium wire, when heated side by side in a uniform-temperature enclosure.

A reasonable degree of uniformity of temperature in the neighbourhood of the hot junction is desirable in the case of the gold- and palladium-point determinations. It can be shown that a temperature difference of 1° C. between the ends of the palladium wire at the melting point will give rise to an error in the thermocouple reading

of + 25 or − 35 microvolts, according to whether the palladium/platinum–13%-rhodium or the palladium/platinum junction is at the higher temperature. In the case of such a violent gradient there would be no steady e.m.f. reading of the couple immediately before the break of the junction. The corresponding e.m.f. differences at the gold point are smaller, while at the platinum point they are non-existent. Although no special precautions were taken to ensure temperature uniformity in the furnaces employed, other than the use of a furnace tube having a high ratio of length to diameter, the steadiness of reading before rupture of the junction and the reproducibility of the results were taken to indicate that there were no serious errors on this account. Subsequent experiments undertaken to throw further light on this point suggested that it was unlikely that an error exceeding ± 10 microvolts had been introduced from this cause.

The ratio of the electrical resistances at 100° and 0° C. of the palladium wire used was found to be 1·377, indicating a sufficiently high degree of purity.(3) The values obtained for this ratio for the platinum wires of couples *C* and 4 were 1·3916 and 1·3919, respectively. The Comité Consultatif de Thermométrie (4) in 1939 recommended for adoption in the International Temperature Scale specifications that the ratio for the platinum used in resistance-thermometer bulbs and platinum/platinum–rhodium thermocouples employed in realising the International Temperature Scale shall have a minimum value of 1·391.

Discussion of Results.

During the preliminary observations some of the couples gave lower values at the gold points after heating them to the platinum point than they did before. The platinum points in these cases were also unsatisfactory, no constant e.m.f. value being given, but the readings showing a steady rise during the fusion of the junction, which nevertheless was appreciably slower than that of the control couple. This seemed to indicate that these couples had become contaminated, their behaviour conforming to the supposition that the degree of contamination became less as the distance from the hot junction increased; thus, as the bead of platinum advanced up the alloy wire, a greater e.m.f. was given. The presence of this contamination could not be explained, and it was decided to reverse all the couples and recommence the observations.

The results of the observations on the reversed couples are set out in Table I., the four couples of one make being designated by the letters *A*, *B*, *C* and *D*, and the four couples of the other make by the figures 1, 2, 3 and 4. The figures in brackets after each value indicate the order in which the observations were taken. It is to be noted that a high reproducibility of reading at each point was obtained. The mean e.m.f. value of any one of the eight couples

does not differ from the mean of all the couples by more than 1° C. at any of the fixed points. The mean values of the two makes of

TABLE I.—*Summary of E.m.f. Values at the Melting Points of Gold, Palladium and Platinum.*

Figures in brackets indicate the order in which the observations were taken.

Couple.	E.m.f., in Microvolts (for Cold Junctions, 0° C.), at Melting Point of—		
	Gold.	Palladium.	Platinum.
A	11347 (3) 11348 (5)	18188 (4) 18191 (6)	21095 (1) 21105 (2)
Mean	11347·5	18189·5	21100
B	11354 (3) 11351 (5)	18185 (4) 18189 (6)	21105 (1) 21111 (2)
Mean	11352·5	18187	21108
C	11352 (3) 11348 (5)	18185 (4) 18186 (6)	21108 (1) 21113 (2)
Mean	11350	18185·5	21110·5
D	11353 (3) 11352 (5)	18191 (4) 18200 (6)	21123 (1) 21134 (2)
Mean	11352·5	18195·5	21128·5
Means of Couples *A* to *D*	11350·5	18189·5	21112
1	11365 (2) 11363 (4)	18202 (3) 18201 (5)	21119 (1) ...
Mean	11364	18201·5	21119
2	11371 (3) 11363 (5)	18189 (4) 18198 (6)	21119 (1) 21119 (2)
Mean	11367	18193·5	21119
3	11366 (3) 11367 (5)	18187 (4) 18187 (6)	21116 (1) 21113 (2)
Mean	11366·5	18187	21114·5
4	11363 (3) 11362 (5)	18199 (4) 18187 (6)	21116 (1) 21107 (2)
Mean	11362·5	18193	21111·5
Means of couples 1 to 4	11365	18194	21116
Means of all 8 couples	11358	18192	21114

couple at the palladium and platinum points differ only by the equivalent of 0·3° C., but at the gold point the difference is about 1° C. This seems to indicate a slight difference in the form of the e.m.f./temperature relation of the two products; the difference, however, is so small that the mean value of all the couples may be used to draw up reference tables which may be employed with both makes of couple without introducing a significant error.

Table II., giving the mean e.m.f.'s of the thermocouples for every 10° C. from 1400° to 1770° C., has been derived from the data in Table I. in the manner explained below. As already stated, the relation of temperature to e.m.f. of a thermocouple should strictly be derived by comparison with an optical pyrometer reproducing the International Temperature Scale. It is known that in the case of

TABLE II.—*E.m.f./Temperature Calibration of Platinum/13%-Rhodium–Platinum Thermocouples over the Range* 1400° *to* 1770° *C. with Cold Junctions at* 0° *C.*

The e.m.f. values are given to the nearest 0·01 mV., but the absolute accuracy is not claimed to be better than ± 3° C. up to 1600° C. and ± 5° C. above this temperature.

NOTE:—When compensating leads are used, care should be taken to ensure that the two junctions between the compensating leads and the thermocouple wires are at the same temperature, and that this temperature does not exceed 100° C. Otherwise, serious errors may be introduced.

Temperature.	1400° C.	1500° C.	1600° C.	1700° C.
° C.	MV.	MV.	MV.	MV.
0	16·00	17·43	18·81	20·16
10	16·15	17·57	18·95	20·29
20	16·29	17·71	19·08	20·42
30	16·43	17·85	19·22	20·55
40	16·58	17·98	19·35	20·68
50	16·72	18·12	19·49	20·81
60	16·86	18·26	19·62	20·94
70	17·00	18·40	19·76	21·07
80	17·14	18·54	19·89	
90	17·29	18·67	20·02	

platinum thermocouples, of a kind containing either 10% or 13% of rhodium, this relation cannot be expressed in linear or parabolic form on the basis of observations at the three melting points of gold, palladium and platinum. When, however, the range is considerably shorter than from 1063° to 1773° C., and the highest accuracy is not demanded, a parabolic form no doubt suffices. The following procedure has been adopted in deducing such a form over the range from 1400° to 1770° C.: For two of the three points required, the e.m.f. determinations at the palladium and platinum points are used. The gold-point observations are not directly employed, but by comparing them and the palladium-point observations with the

interpolation curve used by the National Physical Laboratory for such couples for the range 1063° to 1555° C., an estimate is obtained of the e.m.f. value at 1400° C., which is then used as the required third point. Since the above-mentioned interpolation curve agreed with those adopted in other laboratories to within the accuracy now aimed at, namely, ± 3° C., this procedure may be regarded as satisfactory. It yields the following equation for the e.m.f./temperature relation from 1400° to 1773° C. :

$$e = -7966 + 19{\cdot}820t - 0{\cdot}001928t^2.$$

From this equation the values in Table II. have been computed. It is estimated that the accuracy of the calibration in terms of the International Temperature Scale is ± 3° C. up to 1600° C. and ± 5° C. beyond this temperature. The calibration of a particular couple may be obtained by the determination of its e.m.f. at two points within the range, most conveniently the melting points of palladium and platinum, by the wire method, and plotting the curve of deviation from the reference table.

Acknowledgments.

The work described in this paper has been carried out at the National Physical Laboratory on behalf of The Iron and Steel Institute. The paper is published on the recommendation of the Liquid Steel Temperature Sub-Committee and by permission of the Director of the National Physical Laboratory.

REFERENCES.

(1) *Bureau of Standards Journal of Research*, 1929, vol. 2, pp. 959–962.
(2) *Metal Treatment*, 1939, vol. 5, No. 20, p. 172.
(3) *Proceedings of the Royal Society*, 1936, A., vol. 155, pp. 303–305.
(4) *Procès-Verbaux des Séances du Comité Consultatif de Thermométrie*, 1939. Paris, 1939 : Gauthier-Villars, Imprimeur-Libraire du Comité International des Poids et Mesures.

CORRESPONDENCE.

Mr. W. C. Heselwood (Central Research Department, The United Steel Companies, Ltd., Stocksbridge, near Sheffield) wrote: The results presented in this paper meet a need that has been felt for some time by providing a reliable high-temperature calibration of platinum/13%-rhodium–platinum thermocouples of British origin. Calibration figures have been available from the U.S.A. National Bureau of Standards,[1] but the impression was that at high temperatures for a given e.m.f. the American calibration gave a temperature markedly higher than that in available British calibrations; the present results confirm this, the differences being:

At 1400° C.	Bureau of Standards approximately	4½° C.	higher than N.P.L.
1500° C.		7½° C.	
1600° C.		10° C.	
1700° C.		9½° C.	

Certainly most of these differences are within the plus or minus limits claimed for absolute accuracy, but it would be interesting to know whether the author thinks that there may be a small consistent difference between thermocouples of American and British origin.

In this experimental work the individual readings have been taken to 1 microvolt, and to do this the precautions described ((i) special battery supply, (ii) very slow rate of heating, ½–1° C. per min.) were necessary, although the results show that reproducibility is only to the nearest 10 microvolts. Fortunately, this is of ample accuracy (better than 1° C.) for the purpose, and experience of palladium-point calibrations in the Central Research Department of The United Steel Companies, Ltd., is that this accuracy is readily obtainable when using mains supply and a rate of heating of approximately 5° C. per min., even with a furnace of less heat capacity than that described by the author. The direction to use special batteries, &c., repeated in the practical guide to which the author refers, seems therefore to be unnecessarily severe for routine calibrations; whilst being perhaps a convenient refinement, it would be a pity if lack of suitable batteries were to influence anyone not to make use of the method so clearly described by the author.

Dr. O. R. J. Lee (Teddington, Middlesex) wrote: This paper appears to be the culmination of the excellent work done by the N.P.L. on the subject of liquid-steel temperature measurements. With the development work virtually completed, it may now seem an easy and obvious method of measuring such temperatures to dip in a protected noble-metal thermocouple. The magnitude of the debt owed by the steel industry to the Liquid Steel Temperature

[1] Summarised by W. F. Roeser and H. T. Wensel, American Institute of Physics Symposium on "Temperature, Its Measurements and Control in Science and Practice," p. 1298. New York, 1941: Reinhold Publishing Corporation.

Sub-Committee and its programme of work is revealed by the fact that American and German papers [1, 2] have condemned the thermocouple method as being impracticable and offering insuperable difficulties.

The paper under discussion gives an e.m.f./high-temperature relationship which can be applied to all new 13% rhodium thermocouples and virtually defines a high-temperature scale, permitting all users to express their results in common terms. Unfortunately, it appears that, if the quick-immersion technique is taken up in America, a preference will exist for the e.m.f./high-temperature relationship obtained by the United States Bureau of Standards.[3] A discussion of such reference curves is the main object of this contribution, but mention will first be made of a few practical points arising from the experimental work reported in the paper.

On pp. 206 P and 207 P, the difficulties of high-temperature measurement close to a source of high potential are discussed. The errors introduced arise because of the very great decrease in resistance of air and ceramic materials at high temperatures, which permits minute currents to pass from the furnace winding and flow through the thermocouple wires and measuring instruments to some point of low (usually earth) potential. The amount of error in any particular case depends on the path traversed by the leakage, which may not be the same in duplicate determinations. For such types of measurement, the furnace casing should be earthed and all sections of the measuring circuit (including so-called insulated leads) very adequately insulated by paraffin wax or high-grade freshly surface-ground ebonite. Leakage effects are variable during the course of an experiment, and it cannot be too strongly emphasised that for accurate work they must be virtually eliminated. Leakage e.m.f.'s can readily be detected by switching off the furnace current and earthing the furnace winding. There is a further possibility of error due to contact potentials, which is presumably meant by the reference in the paper to electrolytic effects between thermocouple wires and refractory insulators at high temperatures. Personal experience, coupled with careful reading of the present paper and that by Fairchild, Hoover and Peters,[4] indicates that extraneous e.m.f.'s arise only from mains voltage-drop effects and contact potentials. Unless all parts of the measuring circuit were insulated, the statement that "leakages from the furnace winding were avoided by arranging that the insulators covering the thermocouple wires touched neither each other nor the furnace walls" carries little weight.

[1] K. Guthmann, *Stahl und Eisen*, 1937, vol. 57, p. 1247.

[2] L. O. Sordahl and R. B. Sosman, American Institute of Physics, Symposium on "Temperature, Its Measurement and Control in Science and Industry," p. 928. New York, 1941: Reinhold Publishing Corporation.

[3] W. F. Roeser and H. T. Wensel, *Bureau of Standards Journal of Research*, 1933, vol. 10, p. 275.

[4] *Bureau of Standards Journal of Research*, 1929, vol. 2, p. 959.

A practical proof of this matter was obtained by the writer with a liquid-steel temperature set-up using a self-contained quick-immersion potentiometer on an anti-vibration sponge-rubber mat. Observations were made at about 1500° C. in a small tube furnace. Although the couple wires were in twin-bore insulators which touched the side of the furnace, no leakage effect was observed on switching the furnace current off and on, and when an open circuit was obtained after the palladium calibration the potentiometer indicated zero e.m.f. This was ascribed to the insulating properties of the rubber mat. When the experiments were repeated with an external galvanometer resting on an earthed plate, leakage e.m.f.'s of different magnitudes were apparent before and after the palladium determination.

The furnace design and method of operation described in the paper were justifiably elaborate for determining a reference curve, but once this has been accurately done, works checks on thermocouples for contamination do not need such refined apparatus and methods. I have had very satisfactory results with a platinum-strip-wound alumina tube furnace 4 in. long and ½ in. in internal diameter. It is my opinion that for checking used couples a short furnace is essential to reproduce the steep temperature gradients existing near the junction of a couple when immersed a few (2 or 3) inches in liquid steel. Contamination of a thermocouple only makes itself manifest in the e.m.f. reading when the contamination is in a zone of temperature gradient, and a very false impression of the contamination effect on an immersion reading would be obtained from a calibration in a furnace with a long uniform temperature zone. The small furnace described worked satisfactorily from the A.C. mains supply and the temperature could be judged sufficiently well by the furnace current without the use of a control couple. The main error appeared to be due to stress in the palladium bridge causing premature breakage, but if no results were accepted where the palladium had not run down to smooth beads on each couple wire, very consistent results were obtained.

For the platinum point, surprisingly good reproducibility was obtained by moving an electric arc slowly up to the couple junction mounted horizontally. Efficient insulation of the measuring circuit is essential, but the aforementioned rubber mat was sufficient for the potentiometer.

Although these methods seem crude and would not be tolerated for a moment in work to obtain a thermocouple reference curve, they have been described to counteract the possible supposition that works checking for contamination would require the same equipment and battery operation as are described in the paper.

Turning, now, to more fundamental points, the equation put forward as representing the e.m.f./temperature characteristics of a 13% rhodium couple at 1400–1600° C. involves a rapid decrease in thermo-electric power with rising temperature ($de/dt = 19{\cdot}820 - 0{\cdot}003856\ t$). However, the mean of a number of N.P.L. cali-

brations up to 1600° C. made prior to the work described in this paper and constituting the standard curve for the Sheffield Smelting Company's rhodium couples, indicates a thermo-electric power which increases with increasing temperature. The data are shown in Fig. A, together with the thermo-electric power values from the U.S. Bureau of Standards' reference curve.

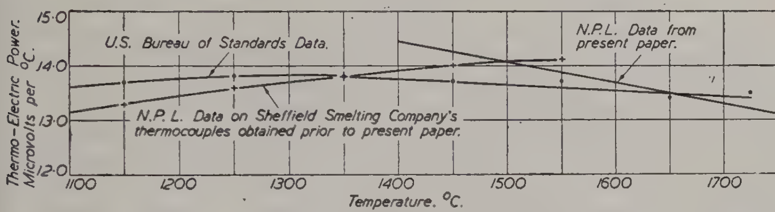

FIG. A.—Thermo-Electric Power of 13% Rhodium Thermocouples.

A further point of which the significance is increased by the use of an estimated e.m.f. at 1400° C., is that a cubic equation cannot be made to fit the four points 1063°, 1400°, 1555° and 1773° C. The paper thus presents us with a temperature scale having a well-marked inflection where the old and new determinations meet.

The magnitude of the discrepancy is shown by Fig. B, in which the mean e.m.f. of the Sheffield Smelting Company's couples as determined by the N.P.L. and also the present published values are compared with the Bureau of Standards' figures.

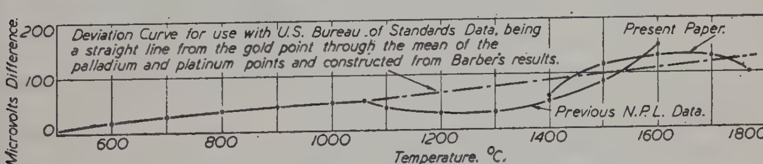

FIG. B.—Electro-Motive Force Difference, N.P.L. figures minus U.S. Bureau of Standards figures.

It is true that the deviation is not serious from a practical point of view in measuring liquid-steel temperatures. A linear deviation curve from the Bureau of Standards' figures, based on Barber's values at 1063° and 1773° C., gives values less than 20 microvolts different from the present tabulated values in the range 1500–1700° C. In the range 1200–1400°, however, the position is not so good. Differences of 50 microvolts arise.

To decide which set of figures is most likely to be correct, it is necessary to refer to the basis of the curves. The Bureau of Standards obtained their 13% rhodium reference curve from comparisons with a 10% couple which had been standardised by fixed points and optical pyrometer at 1063°, 1250°, 1400° and 1773° C. The form of the 10% reference curve is substantiated by a Bureau of Standards optical comparison with a number of couples at 1500° C.

when in most cases the agreement was within 1° C.[1] It is also substantiated by the shape of the thermo-electric-power/temperature curve, which is in good agreement with Day and Sosman's figures based on gas-thermometer comparisons.[2] The N.P.L. calibration of the Sheffield Smelting Company's 10% couples is not in good agreement with the latter.

The American figures seem more reliable than the N.P.L., and, using the values for gold, palladium and platinum in the present paper, a straight-line deviation curve to be applied to the Bureau of Standards' reference curve can be obtained in three ways: By using (*a*) gold and palladium values, (*b*) gold and platinum values or (*c*) gold and the mean line passing between palladium and platinum. These give differences of about 10 microvolts in the liquid-steel temperature range and indicate sufficient reliability for such a straight-line deviation plot. There is, however, a certain possibility that the Bureau of Standards data are not exact in this range because experience shows that the palladium calibration e.m.f. is always greater than a mean straight-line deviation curve indicates, whilst the platinum calibration e.m.f. is always less.

It appears possible that a cause of this might lie in the method used at the platinum point, which assumes a smooth e.m.f./temperature relationship right up to and including the melting point of one of the couple wires.

As a possible indication of the reliability of the method, the writer has experimented with a platinum-gold couple, making observations up to and including the melting point of gold. A triple-junction couple was made from 10% rhodium, platinum and gold wires. Observations of the rhodium-platinum and rhodium-gold e.m.f.'s on a rising temperature gave the variation of the platinum-gold e.m.f. with temperature.

Observations every 8° and every 4° close to the melting point of gold gave thermo-electric power values within $\pm$ 0·4 microvolts per °C. from a straight line, except for two observations 0·9 and 0·6 microvolts per ° C. away. A quadratic e.m.f./temperature relationship formed on three calibration points gave results agreeing with observations to within $\pm 0{\cdot}2_3$° C., and at the melting of the gold wire the temperature given by the observed e.m.f. was 1062·9° C.

The use of the gold point in a gold-platinum couple is thus confirmed as being reliable and the inference is that the platinum point on a platinum/platinum-rhodium couple is also likely to be reliable.

A further investigation of the high-temperature scale comparing optical pyrometers and thermocouples at about six points between 1063° and 1773° C. (providing data for the calculation of one or two cubic equations) would indicate the possibility of improving the United States Bureau of Standards' reference curves.

[1] W. F. Roeser and H. T. Wensel, American Institute of Physics, Symposium on "Temperature, Its Measurement and Control in Science and Industry," p. 303. New York, 1941: Reinhold Publishing Corporation.

[2] A. L. Day and R. B. Sosman, *Carnegie Institute, Washington,* 1911, *Publication No.* 157, p. 119.

Summarising, it would seem preferable to regard the present work as justification for the use of a straight-line deviation curve from the United States Bureau of Standards' reference curve at high temperatures, thus retaining one international basis of measurement having a smooth variation in the whole of the temperature range.

An additional point worthy of note if high accuracy is desired at elevated temperatures is that a 10% rhodium couple has a slower rate of change of thermo-electric power with temperature and should be capable of more accurate interpolation between calibration points than a 13% rhodium couple. Day and Sosman showed that 15% and 20% rhodium couples had very markedly curved e.m.f./temperature relationships above 1400° or 1500° C., whilst a 10% couple was not far from linearity

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AUTHOR'S REPLY.

Mr. Barber wrote : In reply to Mr. Heselwood, there is a difference between the e.m.f. values of platinum/13%-rhodium–platinum thermocouples of American and British origin amounting to about 40 microvolts at the melting point of gold (1063° C.) and about 120 microvolts at the melting point of palladium (1555° C.), equivalent to 3° and 9° C., respectively, the British thermocouples giving the higher e.m.f. These values should be quite independent of the shape of the reference curve adopted in the two countries.

Dr. Lee is right in emphasising the need for careful insulation of the measuring circuit, but even after such precautions have been taken there is still a risk of leakage when the thermocouple is in contact with the furnace wall over an appreciable length because of the potential gradient in the furnace winding. It was for this reason that the insulators were not allowed to touch the furnace tube.

The method of carrying out the observations may be somewhat more elaborate than is necessary for works practice. The way in which this may be modified and yet still give satisfactory results is mainly in the direction of using a furnace of greater heat capacity than those described, so that it may be operated from the mains supply to give an easily controlled rate of temperature rise. If it is agreed that a satisfactory result is not obtained unless a halt or at least a marked lessening in the increase of e.m.f. of the test couple is observed then a control couple is essential in order to distinguish a melting-point halt from a steadying of the furnace temperature. Dr. Lee is of the opinion apparently that it is unnecessary to observe the stationary value of the e.m.f. before rupture but merely to measure the e.m.f. of the couple at the moment of the break. In my experience this method can lead to appreciable errors, not only in giving, as he mentions, a low e.m.f. due to a premature break of the junction, but also a high value as a result of the couple wires being drawn together by surface tension of the molten bead for a short time before the rupture occurs. The great advantage of observing the halt in the e.m.f. value appears to me to be that sufficient confidence in the result is gained to justify

reliance on a single determination, whereas with the other method several determinations would be necessary to establish the validity of the result obtained.

With regard to the question of contaminated couples there does not appear to be any real advantage in standardising contaminated couples, since it is unlikely that the temperature gradient in the standardising furnace will coincide with that along the couple when in use. A short furnace or a flame may be used to detect contamination, by joining a new similar wire at the hot junction and attaching the other ends of the new and old wires to a galvanometer or potentiometer and passing the wires through the furnace or flame. The best check on contaminated couples in liquid-steel temperature measurement by the quick-immersion method is obtained by a comparison in the steel bath of a new and the old couple immersed together in the same sheath. This procedure has been recommended and used.

A discussion on the general shape of the e.m.f./temperature curve for the platinum/13%-rhodium–platinum thermocouple is, I feel, outside the scope of the present paper. The reference table given here was drawn up for the limited range 1400–1770° C. to meet the particular needs of the users of the quick-immersion method of liquid-steel temperature measurement, and there is little doubt that by its use sufficiently accurate calibrations of this type of thermocouple may be obtained. There is some evidence, based on observations at the melting points of gold, palladium and platinum, to suggest that there is a difference of curvature between the e.m.f./temperature relationship of thermocouples of British and American origin; there even appears to be a slight difference of curvature between the two British makes of couple, as pointed out in this paper. The question of the former differences cannot be resolved by mere inspection of the reference tables; the problem would be best dealt with by an interchange and comparison of the thermocouples of the two countries. In view of this it would not be advisable to assume identity of curvature in the e.m.f./temperature curves of thermocouples of British and American origin by using a straight-line deviation from the American reference tables for thermocouples of British origin as suggested by Dr. Lee.

With regard to the thermo-electric-power/temperature relationship of the reference curve at present in use at the N.P.L., this is a smooth curve, but shows a change from increasing to decreasing thermo-electric power towards the top of the range, as does the U.S.A. National Bureau of Standards reference table, with which it agrees up to 1300° C. It is about 0·4 microvolt per ° C. higher at 1500° C. and in agreement at 1700° C. The N.P.L. curve has, of course, been modified as a result of the present determinations at the melting point of platinum.

To summarise, there is a difference of curvature between American and British standard tables of the platinum/13%-rhodium–platinum thermocouples in the range 1100–1700° C. amounting to a maximum of 3° C. at 1300° C. This may be wholly or partly accounted for by real differences between the products of the two countries.

THE POSITIONS OF THE CARBON ATOMS IN MARTENSITE.*

By N. J. PETCH, B.Sc., B.Met. (Cavendish Laboratory, Cambridge).

Summary.

It has been found impossible to obtain direct evidence of the positions of the carbon atoms in martensite. Indirect evidence can, however, be obtained from the change in cell dimensions with carbon content and from the fact that the structure is tetragonal.

It is concluded that the carbon atoms are at the mid-points of the long edges of the martensite tetragonal cell and at the centres of the faces perpendicular to them. These positions are crystallographically equivalent. In them the carbon atoms are surrounded by octahedra of iron atoms. There is never enough carbon in solution for all these positions to be filled. This would require 2·0 carbon atoms per unit cell, whereas, with the observed maximum carbon content, there will be an average of only 0·16 per unit cell. The behaviour is as if, at the most, each position were one-twelfth filled.

The martensite structure is interesting because of its being tetragonal at all, and because the interstices utilised by the carbon atoms are not those which would normally be considered the largest.

Introduction.

Fink and Campbell [1] first showed that in martensite there are iron atoms on a body-centred tetragonal lattice. Evidence of the positions of the carbon atoms is, however, lacking. An attempt has therefore been made, by annealing at 90° C., to obtain martensite giving sharp X-ray lines. From the intensity of these it might be possible to obtain direct evidence of the carbon positions. Decomposition, however, takes place more readily than line-sharpening. The indirect evidence of the carbon positions has, therefore, to be considered.

Density measurements [2, 3] have eliminated the possibility of carbon replacing iron atoms, and the view most generally held is that the carbon atoms are in the interstices of the iron lattice. There is disagreement, however, about which of the interstices are used. There have been two proposals, one by Hägg,[3] the other by Seljakow, Kurdjumoff and Goodtzow.[4] There are three possible types of interstices. These are at the centres of triangles, tetrahedra or octahedra of iron atoms. With the cell dimensions corresponding to 0% carbon, none of them is large enough to accommodate a carbon atom of radius 0·77 Å. without displacement of the neighbouring atoms. As a consequence, with an increase of carbon content there is an increase of cell size. It is not, however, immediately possible to decide where the carbon atoms must be located

* Received August 19, 1942.

in order to give the observed dimensions, because with the practical carbon contents only a fraction of the available interstices of any kind can be filled.

In the analogous case of austenite, the carbon atoms enter the largest interstices.(5) In martensite the triangular interstices are very much smaller than the others and can be neglected. With the dimensions for 0% carbon, in the tetrahedral interstices the distance from the centre to each iron position is 1·60 Å., leaving 0·35 Å. in excess of the iron atomic radius. In the octahedral interstices four of the iron atoms are at a distance which leaves 0·77 Å. excess. The other two, however, leave only 0·18 Å. Assuming atoms to behave as hard spheres, the tetrahedral interstices must be considered the largest. For this reason Hägg (3) concluded that these are the ones occupied by the carbon atoms.

Seljakow, Kurdjumoff and Goodtzow,(4) however, approaching the question from the relationship between austenite and martensite,

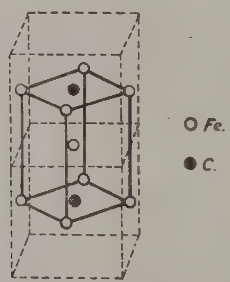

Fig. 1.—The Tetragonal Representation of Austenite.

considered that the carbon atoms were at the centres of the faces perpendicular to the long axis of the tetragonal cell. The face-centred cubic austenite can be represented as a body-centred tetragonal cell (Fig. 1). They assumed that during the transformation to martensite the identity of the tetragonal cell was retained, while there was adjustment to a smaller axial ratio. They further assumed that in austenite the carbon atoms were at the centres of the face-centred cubes and that during the martensite transformation they remained in these interstices. These are octahedral interstices in the location that they proposed. They made no mention of the positions at the mid-points of the long edges of the cell, which, actually, are crystallographically equivalent.

The Change in Martensite Dimensions with Carbon Content.

Some useful information about the carbon location can be obtained from the change in martensite dimensions with increasing carbon content.

With the dimensions of carbon-free martensite none of the interstices is large enough to accommodate a carbon atom without displacement of the iron atoms. An increase in the size of the interstices used by the carbon is therefore to be expected as the carbon content increases. Consistent measurements of the martensite dimensions have been made by Öhman,(6) Honda and Nishiyama,(2) Hägg (3) and others. The short a axis decreases slightly over the observed range of composition, while the c axis increases more rapidly.

In α-iron all the tetrahedral and all the octahedral interstices are identical, but in martensite the tetragonal structure results in there being two types of tetrahedral interstices and two types of octahedral interstices. The dimensions and location of these are shown in Fig. 2. The variation in size of the interstices with change of carbon content is given in Table I.

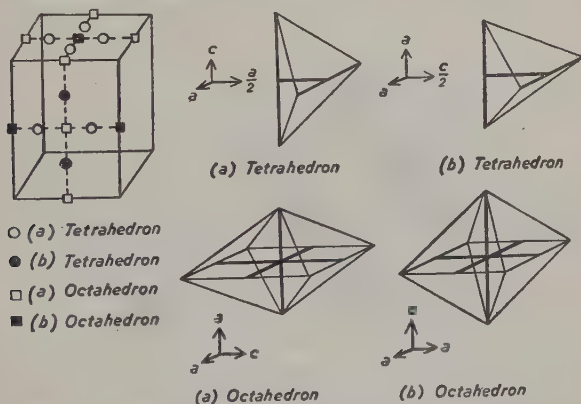

Fig. 2.—The Location and Dimensions of the Interstices in Martensite. The axial lengths are shown at the side of each interstice.

Table I.—*The Variation of the Size of the Martensite Interstices with Carbon Content.*

Centre–Iron Distances, Å. Interstice—											
Tetrahedral (*a*).			Tetrahedral (*b*).			Octahedral (*a*).			Octahedral (*b*).		
No.	0% C.	1·4% C.	No.	0% C.	1·4% C.	No.	0% C.	1·4% C.	No.	0% C.	1·4% C.
2	1·599	1·587	4	1·599	1·610	2	1·430	1·420	2	1·430	1·517
2	1·599	1·675				4	2·023	2·078	4	2·023	2·008

In type (*a*) tetrahedra, Fig. 2, the four iron atoms are all at the same distance from the centre of the interstice when the martensite is carbon-free. In the presence of carbon, however, although two of

the centre–iron distances increase, the other two decrease progressively. Accommodation of the carbon atoms at the centre of this type of interstice is, therefore, very unlikely. In type (*b*) tetrahedra the four iron atoms are always equidistant from the centre, and the distance increases with the carbon content. The increase seems too slight, however, to make this location probable.

In the octahedral interstices two of the centre–iron distances are considerably shorter than the other four. Type (*a*) octahedra are eliminated, since the short centre–iron distances decrease progressively as carbon is added. The behaviour of the type (*b*) octahedra is, however, more what would be expected to result from the presence of carbon in them. The short centre–iron distances increase rapidly. The fact that the other four centre–iron distances decrease slightly over the observed range of composition is rather unexpected but not completely unreasonable. These are distances such as AF, Fig. 3, and depend entirely on the separation of A and B, which

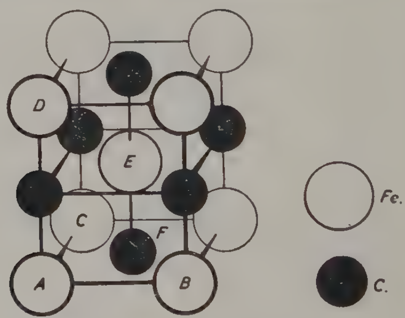

FIG. 3.—The Martensite Structure.

are held apart by E. In α-iron the distance AF would permit accommodation of a carbon atom at F without pressure on A. There would, however, be considerable pressure on E. It is impossible to predict what secondary adjustments in dimensions would result from displacements of atoms such as E when only a few F positions are filled. There would, however, be a definite tendency for AF to decrease, since the separation of E from A and B is increased. Little decrease would be possible, owing to pressure by the carbon atom on A.

Consideration of the martensite dimensions thus reduces the possible location of the carbon atoms to type (*b*) tetrahedra or type (*b*) octahedra, and the latter appears the more probable.

THE TETRAGONAL STRUCTURE OF MARTENSITE.

It seems possible to make a decision between the octahedral and the tetrahedral interstices from the fact that the martensitic supersaturation of α-iron results in a tetragonal structure.

Seljakow and his co-workers considered that this effect was merely due to the low concentration of carbon. Their argument is as follows: If all the octahedral interstices in α-iron are filled a cubic structure will result. With the practical composition, however, only a fraction of the interstices can be occupied, and, at any instant, there will not be more than one interstice occupied per unit cell. In Fig. 3, with the martensite dimensions, insertion of a carbon atom at F will exert a pressure on the iron atom at the centre of the cell, but not on those at the corners. There will be no other carbon atoms in the unit cell. Thus there will be need for expansion of the cell in the direction AD, but not in the directions at right angles, and a tetragonal structure will result.

This explanation of the tetragonal structure is not satisfactory. If carbon atoms are considered to be randomly distributed amongst a number of unit cells, in some the expansion will be in the direction AD, but in others in the directions AB or AC. X-rays will show the average of these distortions, which will not give a tetragonal structure but will appear merely as an expansion of the cell, with the retention of the cubic structure. When there is not enough carbon in solution for all the equivalent interstices to be filled, the resultant effect is as if each is partially filled.

The tetragonal structure can be satisfactorily explained in the following manner: In α-iron all the octahedral interstices are equivalent. If all are partially filled a cubic structure results. A tetragonal structure can only be obtained, using the octahedral interstices, if, in spite of their equivalence, a differentiation is made amongst them and only selected ones are utilised by the carbon atoms. If a particular axial direction in the cubic structure is chosen and only the octahedral interstices at the mid-points of the edges parallel to this direction and at the centre of the faces perpendicular to this direction are utilised, a tetragonal structure results. The chosen direction then becomes the c axis. The octahedral interstices utilised are of the type (b), which, it has been seen above, are satisfactory from the point of view of the change in dimensions with increasing carbon content. Thus, by selective utilisation of the octahedral interstices the tetragonal structure can be obtained.

When, however, the tetrahedral interstices are considered, the tetragonal structure decides against them. Again, in the cubic structure all the tetrahedral interstices are equivalent, and if they were all partially filled the cubic structure would be obtained. It has already been seen that only the (b) tetrahedral interstices are possibilities. But no matter how the tetrahedral interstices are selectively filled, the tetragonal structure of the observed type cannot be obtained.

The conclusion from the indirect evidence is, therefore, that the carbon atoms are in the octahedral interstices at the mid-points of the long edges of the martensite tetragonal cell and at the centres of the faces perpendicular to them. These positions are crystallo-

graphically equivalent. This structure is shown in Fig. 3. There is never enough carbon in solution for all the positions to be filled. This would require 2·0 carbon atoms per unit cell, whereas, with the observed maximum carbon content, there will be an average of only 0·16 per unit cell. The behaviour is as if, at the most, every interstice was one-twelfth filled.

This structure of martensite has a number of interesting features. Particularly interesting is the question why there is, as a result of supersaturating α-iron, a tetragonal structure at all. Why does the differentiation arise between the octahedral positions, which, from the point of view of α-iron, are completely equivalent? A possibility is that the carbon positions are controlled by the relationship between austenite and martensite. This transformation is almost certainly accomplished by an atomic gliding, during which it is possible that the carbon atoms cannot escape from the interstices that they occupy in austenite. Such a view, however, must remain purely speculative while there is the present lack of an exact knowledge of the atomic mechanism of the austenite–martensite transformation.

Another interesting question is why the octahedral interstices are used instead of the tetrahedral ones, which are larger. It would be a very simple matter for a carbon atom to move from an octahedral position. All that is necessary is that it should move aside from between the two iron atoms most closely pressing upon it. Perhaps the assumption that atoms behave as hard spheres is not always the correct picture. The octahedral interstice, with two short and four long centre–iron distances, may actually be effectively larger for carbon accommodation than the tetrahedral with four medium centre–iron distances.

Other Theories of Martensite.

There have been various suggestions, for instance by Desch [7] and Sauveur,[8] that martensite consists of α-iron with a very fine precipitate of cementite. If, however, there were actual separation of the cementite, there would be no reason for the tetragonal structure.

In some cases of precipitation, for example $CuAl_2$,[9] an intermediate stage occurs in which there is no actual separation from the parent lattice. Where there is such an association of the lattices, one of the structures may be affected to a certain extent. The normal effect is, however, on the precipitated structure, hence this could not explain the distortion of α-iron into a tetragonal structure, since the α-iron would be the parent lattice. The distortion from the cubic structure could arise if there were carbon atoms partially interstitial in the α-iron, in the plane, common to the cementite and α-iron. It is, however, difficult to see how there could be any such fitting together of the known cementite and martensite lat-

tices. Against any suggestion of cementite formation there is the fact that it implies a certain amount of diffusion of the carbon atoms. This is rather inconsistent with the extreme rapidity of the reaction and its independence of the cooling rate. It is not impossible, however, that, on account of the ease of the tempering action, most martensites contain a certain amount of precipitated cementite.

Honda and Nishiyama [(2)] have proposed a cubic β-martensite, but strong evidence against this has been put forward by Hägg.[(3)]

The author would like to thank Professor Sir Lawrence Bragg, F.R.S., and Dr. H. Lipson for their criticism and their interest in this work. The subject forms part of a programme of research supported financially by the Iron and Steel Research Council.

REFERENCES.

(1) Fink and Campbell: *Transactions of the American Society for Steel Treating*, 1926, vol. 9, p. 717.
(2) Honda and Nishiyama: *Science Reports of the Tôhoku Imperial University, Sendai*, 1932, vol. 1, No. 21, p. 299.
(3) Hägg: *Journal of The Iron and Steel Institute*, 1934, No. II., p. 439.
(4) Seljakow, Kurdjumoff, and Goodtzow: *Zeitschrift für Physik*, 1927, vol. 45, p. 384.
(5) Petch: *Journal of The Iron and Steel Institute*, 1942, No. I., p. 111 P.
(6) Öhman: *Journal of The Iron and Steel Institute*, 1931, No. I., p. 445.
(7) Desch: "The Chemistry of Solids," p. 130. Cornell University Press, 1934.
(8) Sauveur: *Science Reports of the Tôhoku Imperial University, Sendai*, 1936, Honda Anniversary Volume, p. 815.
(9) Preston: *Philosophical Magazine*, 1938, vol. 7, No. 26, p. 855.

CORRESPONDENCE.

Mr. TAYLOR LYMAN (University of Notre Dame, Notre Dame, Indiana, U.S.A.) wrote: The author refers to two earlier proposals for the positions of the carbon atoms in tetragonal martensite. Öhman [1] and Johansson [2] also have offered suggestions. The existence of C_2 groups in the interstices of the iron lattice, as suggested by Öhman, appears improbable. The structure suggested by Johansson is deserving of mention, especially because of its similarity to that proposed by Petch. Fig. 6*b* of Johansson's paper shows, in fact, the same interstitial positions in the tetragonal cell as are drawn in Fig. 3 of this paper. Johansson's "r'-spaces" correspond exactly to the "(*b*) octahedron" interstices of Petch. (It is to be noted that there is a confusion of terms in Johansson's paper. The positions called r and r' in the text are given as γ and γ', respectively, in his Fig. 6. There can be no uncertainty as to the meaning; the symbols γ and γ' do not appear at all in the text.) Johansson thought it especially noteworthy that it is only when the r'-spaces, and not the other octahedron interstices, are considered that a tetragonal structure is produced. Apparently he regarded the mechanism of martensite formation as consisting of a contraction along the c axis of the pseudo-body-centred tetragonal austenite and expansion in the two a directions to produce tetragonal martensite having the observed cell dimensions, for he stated that if his suggested structure were real, martensite could be formed from austenite without carbon movement.

Much has been written about mechanisms whereby austenite transforms to martensite and the author states on p. 226 P that the transformation is almost certainly accomplished by atomic gliding, during which it is possible that the carbon atoms cannot escape from the interstices that they occupy in austenite. It is of interest to examine the author's proposed structure of martensite in connection with the most recently advanced mechanism of martensite formation, that of Greninger and Troiano.[3] This mechanism is the only one available which predicts both the lattice relationships of austenite and martensite and the orientation habit of the martensite plate with respect to the austenite lattice. It is based upon an X-ray and microscopic study of the martensite transformation in steels containing about 22% of nickel and 0·8% of carbon. According to Greninger and Troiano, the martensite crystal is formed from an austenite crystal almost entirely by means of two homogeneous shears.

[1] E. Öhman, *Journal of The Iron and Steel Institute*, 1931, No. I., p. 445.

[2] C. H. Johansson, *Archiv für das Eisenhüttenwesen*, 1937–38, vol. 11, p. 241.

[3] A. B. Greninger and A. R. Troiano, *American Institute of Mining and Metallurgical Engineers, Technical Publication No.* 1338. A summary of this paper has been published in *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1941, vol. 145, p. 289.

A homogeneous shear on the plane of the martensite plate (the habit plane, which is a high-indices plane in the matrix austenite) in the average experimentally determined direction and through an angle of 11°, followed by a second homogeneous shear on the (112) martensite plane in the $[11\bar{1}]$ direction, with the shear angle equal to 13°, results in the (020) austenite plane becoming (within 1° in orientation) the (110) plane of the tetragonal martensite lattice. It seems safe to assume that all carbon atoms in austenite are on (020) planes. If the carbon atoms take part in the shearing movements of martensite formation they will then be located on (110) martensite planes after transformation by this mechanism. According to Petch's Fig. 3, all carbon atoms are on (110) planes of martensite. Furthermore, in none of the other three types of positions (types (*a*) and (*b*) tetrahedral and type (*a*) octahedral) considered by the author do any of the carbon atoms occur on the (110) plane of martensite.

This result, that only type (*b*) octahedral positions will be occupied, can be obtained by transforming the austenite lattice stereographically, since only the movements of planes are considered. Information concerning the movements of any given atom during transformation can be obtained by methods of descriptive geometry, which in the present case are laborious to carry out.

It should be stated explicitly that the following three assumptions have been made :

(1) That the carbon atoms in austenite are in the largest, *i.e.*, the octahedral, interstices, and therefore lie on (020) austenite planes.

(2) That the Greninger-Troiano mechanism is operative.

(3) That the carbon atoms undergo the same shearing movements during martensite formation as the iron atoms do.

The author has remarked that the martensite structure is interesting because of its being tetragonal at all. In this connection, Greninger and Troiano state : "For the transformation face-centred cubic to body-centred cubic [by shear], a pseudo body-centred tetragonal lattice of axial ratio greater than one will always form. . . . The continuation of the transformation to the final cubic form may be hindered by the presence of certain solute atoms ; notably, carbon is responsible for the retention of the tetragonal lattice of martensite in steel. For the martensite transformation in iron-nickel alloys, the tetragonal stage is not retained."

From the point of view of formulating a complete statement of the atom movements which take place when martensite transforms to cementite (or to crystal structures transitional to cementite) during tempering, knowledge of the positions of the carbon atoms in martensite is also of importance. (X-ray evidence for a transition structure in tempered iron-carbon alloys containing 1·4% of carbon

has recently been advanced by Arbusow and Kurdjumow.[1] When the mechanism of the change from tetragonal martensite to $\alpha + Fe_3C$ is better understood an explanation of the property changes during tempering may be possible. It may be mentioned that the author's martensite structure is not inconsistent with the views of Honda and Nishiyama as to the existence of two forms of martensite.

AUTHOR'S REPLY.

The AUTHOR wrote in reply: I would like to thank Mr. Taylor Lyman for his careful examination of this paper. Öhman's suggestion of C_2 groups was not mentioned, as it appeared rather improbable; Johansson's support for the proposed structure of martensite had, however, been overlooked.

Johansson's statement about forming the martensite structure from austenite without carbon movement is not clear. On Mr. Taylor Lyman's interpretation the mechanism of Seljakow, Kurdjumoff and Goodtzow is assumed. This mechanism is too simple. Although the austenite-martensite transformation is in effect a reduction of the c axis of the pseudo-body-centred tetragonal austenite and an expansion in the a directions, it is not merely a movement of the iron atoms together or apart, but involves certain glide movements of planes of atoms. Consequently, for example, basal planes of tetragonal austenite may or may not become basal planes of martensite, depending upon the transformation mechanism. The carbon location will thus depend upon the details of the mechanism. The analysis showing that the proposed structure would result from the operation of the Greninger-Troiano mechanism, assuming that the carbon atoms do not escape from the interstices that they occupy in austenite, is very interesting. I had contented myself with considering that the martensite structure might arise from the trapping of the carbon atoms, and had refrained from adopting any particular mechanism for the transformation, since the previous paper by Greninger and Troiano [2] leaves this matter unsettled for plain carbon and low-alloy steels.

Mr. Taylor Lyman points out that the Greninger-Troiano mechanism has a body-centred tetragonal cell as a necessary intermediate step in the γ–α transformation. It is still remarkable, however, that the carbon can prevent completion of the change to a body-centred cubic structure. If the carbon atoms moved aside from between the iron atoms most closely pressing upon them into the larger tetrahedral interstices, the change could be completed.

[1] M. Arbusow and G. Kurdjumow, *Journal of Physics* (*U.S.S.R.*), 1941, vol. 5, pp. 101–108.

[2] Greninger and Troiano, *American Institute of Mining and Metallurgical Engineers, Technical Publication No.* 1212: *Metals Technology*, 1940, vol. 7, Aug.

This raises a point that was perhaps not made clear in the paper. The tetragonal structure might be merely the particular step in the glide movement at which the γ–α transformation is arrested when martensite is formed. The structure might be unconnected with the presence of carbon atoms, except in so far as in their presence the transformation is arrested at this step. The observed type of variation of axial ratio with carbon content shows, however, that the tetragonality is a direct result of the presence of the carbon atoms in the lattice, and reflects the displacement of the iron atoms which is produced by them.

The proposed martensite structure is not inconsistent with the possibility of the existence of a cubic martensite such as that proposed by Honda and Nishiyama. Indeed, as pointed out, movement to tetrahedral interstices appears very easy. Hägg's work, however, must not be forgotten.

A REVIEW OF BASIC OPEN-HEARTH PRACTICE AT AN AUSTRALIAN PLANT.[1]

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(Figs. 10 to 13 = Plates IV. and V.)

SUMMARY.

The author gives a comprehensive description of the plant and practice at the steelworks of Australian Iron and Steel, Ltd., Port Kembla. The plant is situated within 15 miles by rail of several collieries owned by the Company; the limestone is brought 74 miles by rail from Marulan; red hematite ores, low in phosphorus, are shipped from the Whyalla deposits to Port Kembla, which is about 1070 miles. The open-hearth department consists of seven fixed furnaces varying from 160 to 240 tons capacity and a 1200-ton hot-metal mixer, the latter receiving metal from 70-ton transfer ladles filled from 120-ton ladles hauled from the blast-furnaces. The open-hearth furnaces are fired with either tar and coke-oven gas or producer gas and coke-oven gas. They all comply with accepted modern standards relating to water-cooling and are equipped with modified Blair ports and water-cooled straight-line gates and valves. The tar is fed at 40 lb. per sq. in. and 200° F., with steam for atomisation at 60–80 lb. per sq. in. and 325° F. The outstanding features of the furnace practice are the high hot-metal/scrap ratio, the heavy ore charge (448 lb. per ton) and the low flux rate. The furnaces are therefore subject to violent and protracted ore boils, resulting in a heavy carry-over of solid particles in the waste-gas stream; in spite of this, three of the furnaces have produced ingots at a rate exceeding 21 tons per hr. During ten years' working improvements in design enabled the 230-ton and 240-ton fixed furnaces to be built which can carry such burdens continuously for campaigns exceeding 36 weeks. Details of these improvements in hearth, slag-pocket and checker-chamber design are given. Five of the seven furnaces are all-basic except for the roof and downtake arches; 95% silica bricks are used for the roofs, the life of which varies with the type of fuel; an average roof life is 370 heats on producer-gas-fired units. Comprehensive descriptions of stockyard operations; charging, melting and tapping practice; ingot-mould design and preparation; slag control; and the production of phosphorised sheet bars, of rimming steel and of alloy and forging steels constitute the last part of the paper.

Introduction.

DURING the past decade the ingot capacity of Australian steelworks has been increased greatly. To-day, twenty open-hearth furnaces have an annual capacity of 1,750,000 tons. Based on a 75% overall yield, this represents an annual consumption of 420 lb. of steel per head of population. The total capital investment is about

[1] Received August 19, 1942.

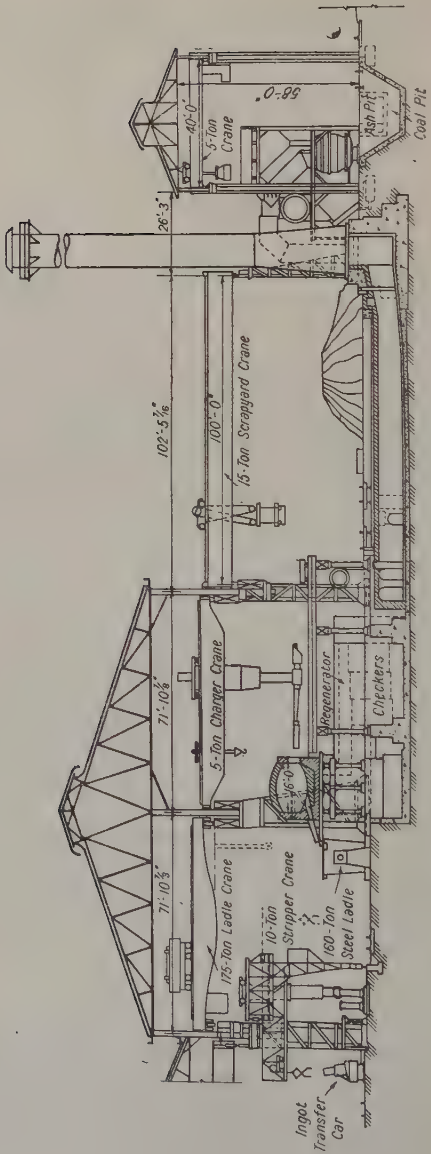


FIG. 1.—Cross-Section through the Open-Hearth Department.

£16,000,000, and the development of Australia as an industrial nation can be attributed mainly to the growth of this industry.

Little information has appeared in steel literature abroad concerning Australian practice, some features of which have been developed to suit local conditions.

The Port Kembla plant of Australian Iron and Steel, Ltd., built since 1928, is the most modern in the country. The open-hearth shop of seven furnaces has an annual capacity of 750,000 tons of steel ingots.

For economic reasons steelmaking at Port Kembla has been based on a high hot-metal furnace burden, which carries up to 450 lb. of iron ore per ton of ingots. The smelting of a rich ore, low in phosphorus and not low in manganese, in the blast-furnaces provides a pig iron of excellent chemical and physical characteristics for basic open-hearth operations. In addition, the open-hearth is supplied with limestone and lump manganiferous feed ore of high quality. These factors combine with a flexible arrangement of suitable fuels fired to furnaces of modern design to ensure a practice notable for quality, high tonnage rates and low cost.

The Port Kembla plant is a unit of an organisation with ramifications wide enough to make it practically independent of the world's markets for all essentials to the manufacture of every type of high-grade steel.

Location of Plant.

The plant is situated at Port Kembla, N.S.W., 56 miles by rail south of Sydney and near to the most southern outcrop of the vast Newcastle Coal Measures. The Company's railroad extends 2 miles to Port Kembla harbour, where there are modern facilities for unloading iron ore from Whyalla, South Australia, and loading the steelworks' products.

Limestone is railed from Marulan, N.S.W., 70 miles inland. Coal supplies are drawn from several collieries owned by the Company on the southern field within a 15-mile radius of the works. Cooling water is pumped from a salt-water channel driven direct to the sea, and soft water is obtained from the Cordeaux dam, which is one of the sources of Sydney's supply.

Plant Layout.

Fig. 1 illustrates a cross-section of the open-hearth department, consisting of seven stationary furnaces. Table I. shows the nominal capacity of each furnace, the year of construction, the bath depth, and the flexibility of the plant with reference to fuel.

From Fig. 1 it will be noted that the gas house is 130 ft. from the melting-shop building, and the furnace gas mains pass beneath the intervening stockyard. Producer gas is made in eight 11-ft. dia. Wellman-Smith-Owen turbine-blown gas machines, each with an

hourly gasification capacity of 7,000 lb. of good bituminous gas coal. The producers are paired to fire *B*, *C*, *D* and *E* furnaces if so required. The coal required per week to operate four furnaces on mixed producer and coke-oven gas is 1,800 tons. A 5-ton gantry crane operating with a suitable grab bucket elevates coal from an adjacent 2,500-ton storage bin to the producer feed hoppers and loads out producer ashes as required. The gas house is equipped with modern instruments and all the facilities necessary for the constant flow to the furnaces of gas of the required quality.

TABLE I.—*Open-Hearth Furnace Data.*

Furnace.	Year Completed.	Nominal Capacity. Tons per heat.	Fuel.	Bath Depth. In.	Regenerators.	Tapping Launder.
A	1939	230	Tar and coke-oven gas only.	40	Double	Bifurcated.
B	1931	200	Producer gas and coke-oven gas. Secondary fuel, tar and coke-oven gas.	38	„	„
C	1933	160		35	„	Single.
D	1935	160		35	„	„
E	1937	160		35	„	„
F	1940	230	Tar and coke-oven gas only.	40	Single.	Bifurcated.
G	1941	240		44	„	„

The stockyard, 630 ft. × 100 ft., is served by two 15-ton combination magnet and crate lifting cranes. A standard-gauge track runs through the yard, and the stocking cranes unload interworks scrap into pans of 36 cu. ft. arranged three to a crate. By lowering a motor-operated pair of lifting arms which engage the hooks on the crate, the cranes lift the stock to the charging benches opposite the furnaces.

The furnace bay is 765 ft. long with a span of 80 ft., and the charging floor elevation is 18 ft. above ground level. The furnaces are charged by two overhead revolving-type machines, each of 5 tons capacity. Hot metal is handled by a 100-ton crane with an auxiliary hoist of 15 tons.

At the western end of the building is a 1,200-ton Pennsylvania-type hot-metal mixer, which receives metal from 70-ton capacity transfer ladles filled from 120-ton Pugh-type ladles hauled from the blast-furnaces. A photograph of this mixer appears in Fig. 10. The mixer is lined with high-alumina bricks with a softening point of 1680° C. which show no after-contraction when heated for 2 hr. at 1400 C. All iron delivered to the mixer and furnaces is weighed over a 100-ton bridge.

An electrically operated fettling machine runs on a broad-gauge track immediately in front of the furnaces. This machine is invaluable for "back-walling" units 18 ft. wide from bank to bank.

The main furnace columns are at 90-ft. centres, and experience on this plant indicates that the present trend abroad to build on 100–105-ft. centres for furnaces of 150 tons capacity or more is sound practice.

All furnaces comply with accepted modern standards relating to water-cooling and are equipped with modified Blair ports and water-cooled straight-line gates and valves.

The casting bay, 945 ft. long and 67 ft. wide, is served by two ladle cranes of 275 tons and 175 tons capacity, respectively. There is also a 45-ton general-purpose crane. Tapped steel runs by either straight or bifurcated spouts into 160-ton capacity conical double-stoppered ladles of riveted construction. Sixteen ladles are in use. Ingots are cast into moulds on fixed stools in single line, and reference to Fig. 1 shows the arrangement of the two combination wall-type stripping and transfer cranes. These machines are supported on track-wheels on a monorail 3 ft. above pit-floor level and on the soaking pits side by an overhead rail. Sufficient clearance above the stripping machine superstructure has been provided to allow freedom of ladle-crane movement.

Ingots are stripped and transferred between the openings of building columns direct to the soaking-pits transfer car, which operates on a broad-gauge track parallel to the casting bay.

Fuel.

Full advantage is taken of the fuel flexibility of the melting shop, as shown in Table I., to maintain tonnage rates, control fuel consumption and improve repairs and maintenance costs. It is well known that an "aged" producer-gas-fired furnace responds in a remarkable fashion when switched to high-pressure fuels, *viz.*, tar or oil. Records of this plant contain many instances of gas-fired furnaces 26–30 weeks old leaking badly through the midfeathers, being changed to tar and coke-oven gas and showing an immediate improvement in fuel rate of almost 50%. The tonnage per hour is also substantially increased, and this practice has an undoubted beneficial effect, not only on the open-hearth but also in the mills, because the flow of ingots is better balanced.

Hence, following the installation of a battery of Otto-Wilputte underjet-fired by-product coke-ovens in 1938, the open-hearth department was completely piped for tar and coke-oven gas. The effect on steelmaking economy was immediate, and a programme of necessary modifications in furnace design was commenced at once.

(a) *Tar.*

The tar fired has the following properties :

Specific gravity at 60° F., 1·19.

Distillation :				
0–200° C.	1·0% by weight.		Naphthalene	6·9%
200–230° C.	5·2%	,,	Free carbon	6·0%
230–270° C.	10·8%	,,	Sulphur	0·4%
270–300° C.	6·1%	,,	Water	1·4%
Total oils	23·1%	,,		

Calorific value, 190,000 B.Th.U. per gal.

Storage is available at the coke-ovens for 300,000 gal. in three tanks. These tanks are steam-heated and tar is drawn off at the surface by floating suction pipes. Tar is railed to the open-hearth in 10,400-gal. steam-heated tank cars and pumped from them to two 10,000-gal. tanks at the open-hearth pump house.

The tankers are emptied by two 3-throw tar pumps each of 3,000 gal. per hr. capacity, and the 4-in. delivery main to the furnace is served by three steam-jacketed rotary gear pumps, each of 1,250 gal. per hr. capacity. The average operating pressure is 105 lb. per sq. in. at 140° F. On the furnace delivery main is a 4-in. Autoclean steam-jacketed tar strainer driven by a ½-h.p., 710-r.p.m., geared double-reduction motor.

A duct beneath the scrap-yard carries the 4-in. furnace main and a 3-in. surplus tar return main. The 4-in. tar main is carried under the charging floor for the full length of the shop, and delivery and return mains are lagged together with a 1-in. steam-pipe. Superheated steam at 350° F. is obtained from tubes in the furnace stack flues and led to the tar and steam manifolds at the control panels of the furnaces.

At each furnace a 2-in. tar delivery pipe is taken off the main and passes through the roof-temperature control valve, tar flowmeter, tar heater and pressure regulator to the manifold. The manifold passes the fuel through a 1½-in. steam-lagged line to each end of the furnace.

The burners are designed to burn a stream of hot tar at high pressure surrounded by a layer of coke-oven gas. The burner consists of two cylindrical solid-drawn tubes with an end-plate connecting both. Cooling water is fed between the inner and outer tubes. Tar from the atomiser is blown through a 1½-in. pipe to a ¾-in. dia. machined nozzle at the burner nose, and the coke-oven gas flows around this pipe in the inner tube.

Tar at 200° F. is burned at 40 lb. pressure, with steam for atomisation at 60–80 lb. pressure and 325° F. While it is not claimed that such burners give ideal results, excellent economy has been obtained by their use. The upkeep is negligible, and, when carefully attended, first-class flame conditions result. On Kembla furnaces best figures are obtained with an hourly consumption of a minimum of 150 gal. of tar and the balance of the heat input made up with coke-oven gas.

(b) *Coke-Oven Gas.*

The average composition and heating value of the coke-oven gas fired to the open-hearth furnaces are:

Specific gravity, 0·360.

Oxygen . .	0·2% by volume.	Methane .	27·7% by volume.
Carbon dioxide .	2·7% ,,	Illuminants	2·0% ,,
Carbon monoxide	7·6% ,,	Nitrogen .	3·0% ,,
Hydrogen .	56·8% ,,		

Calorific value, 530 B.Th.U. per cu. ft.

A 30-in. dia. branch main from the coke-oven steelworks supply line brings the gas to the department. Small downcomers are taken off for ladle drying, tap-hole runners, &c., and a 24–28-in. main is run the full length of the shop just beneath the eaves of the roof and immediately above the furnace control panels. Downcomers of 12-in. dia. carry the gas down through the motorised butterfly valve for roof temperature control. Branch mains, controlled by hand-operated valves within easy reach of the control boards, lead the gas to the furnace ends. An 8-in. tube takes the gas to the composite burners. In order to maintain accuracy of flame diameter the coke-oven-gas nozzle velocity is fairly high, 265 ft. per sec. at 7 in. water-gauge pressure. An illuminated gas pressure indicator is visible from all sections of the charging floor, and the pressure within the system fluctuates between 8 and 20 in. water gauge, depending upon interplant conditions. The proportion of the total heat input to the furnaces derived from coke-oven gas and tar varies within wide limits. A furnace requiring 55×10^6 B.Th.U. per hr. would be fired as follows :

Tar : 150 gal. per hr., 200° F. temperature, 40 lb. pressure, atomised with steam at 70 lb. pressure, and
Coke-oven gas : 50,000 cu. ft. per hr.
Heat input derived from tar, 51·8% ; from coke-oven gas, 48·2%.

Should increased heat input be required the tar supply would be stepped up. Higher proportions of coke-oven gas are not encouraged, because experience has shown that when fired at rates exceeding 50,000 cu. ft. per hr. it tends to " fly " badly to the roof, causing overheating.

(c) *Gas Coal.*

Typical of the gas producer fuels is that drawn from the Kembla colliery, 6 miles distant. The coal is mined from the southern area of the Newcastle Coal Measures. Unfortunately from the producer-gas point of view, most of the coals are essentially steam coals with strong coking properties. An alternative gas coal is obtained from the Company's mine at Lithgow, N.S.W., in the Western Coalfield, 150 miles distant by rail. This may be considered a slightly better gas-machine fuel than the local coal, but each is much inferior as a gas coal to the coals mined from the Greta seam in the Maitland district.

A comparison of the gas-coal analyses is given in Table II. The ash composition and laboratory tests indicate that Mount Kembla coal can be operated with a low air-steam mixture saturation temperature, but in practice the temperature must be kept around 140° F. for safety. It is also slow to burn in the machine, and these two factors are chiefly responsible for the low gasification rates and low " hot " machine efficiencies with this class of coal. The calorific value of producer gas made with local coal is 150 B.Th.U. per cu. ft., the gas containing 7–9% of CO_2. The maintenance of satisfactory

TABLE II.—*Comparison of Gas-Coal Analyses.*

Analyses on dry weight.

Coalfield: Colliery: Size:	Illawarra. Mount Kembla. 2-in. Cobbles.	Western. Lithgow Steelworks. 2-in. Cobbles.	Greta. Hebburn. Cobbles.
Ash. %	11	13	7
Volatile matter. %	23	31	43
Fixed carbon. %	66	56	50
Calorific value. B.Th.U. per lb.	12,990	12,600	13,760
Ash fusion temp. ° F.	2,990	3,000	2,380

producer operation with the fuels available necessitates constant supervision.

Raw Materials.

Table III. shows the compositions of the raw materials available to the open-hearth.

(a) *Iron Ore.*—Ore is drawn from the famous Whyalla deposits in South Australia and shipped approximately 1,070 miles to Port Kembla. Two modern unloaders transfer the ore into 60-ton steel bottom-dumping cars, which are then hauled the 2 miles to the works. As is evident from the Table, the open-hearth has an excellent selection of high-grade ore at its disposal. Most of the ore used in the steelmaking burden and feed is lump manganiferous, but the type of ore used is varied according to the grade of steel required.

The ores are red hematites, low in phosphorus, and they range in manganese content from 0·5 to 30%. All open-hearth ore is screened to + 1 in. before use, the fines being incorporated in basic blast-furnace burdens. Screened ore is loaded directly from bins beneath the screens into charging pans.

(b) *Limestone.*—The limestone, which is of exceptional purity, comes 74 miles by rail from the Company's quarry at Marulan, N.S.W. Open-hearth limestone is well sized to 5–8-in. ring and is free from adherent earthy matter. The large stone is best for open-hearth use. It does not agglomerate on the furnace bottoms as fines would do, and it comes up freely in the later course of the heat. Limestone is dumped directly into pans by the stockyard cranes from bottom-dumping hoppers.

(c) *Burnt Magnesite.*—Magnesite quarried at Fifield, western New South Wales, has been used for many years by the Australian steel industry for bottom-making. Some small consignments of foreign magnesite were imported in the past. All Kembla bottoms contain the Fifield mineral and give satisfactory service.

Preparations are being made to use this magnesite with chrome ore for the manufacture of metal-cased shapes for basic construction.

TABLE III.—*Composition of Raw Materials.*

Analyses on dry weight.

Material:	Iron Ore.			Limestone.	Burnt Magnesite.	Burnt Dolomite.	Raw Dolomite.	Chrome Ore.		Bauxite.	Sea Sand.
Grade:	Foundry.	Basic.	Manganiferous.	5–8 in.	Crushed.	Lump.	Lump.	Lump.		Pebbles.	Windrift.
Origin:	Whyalla. South Australia.			Marulan, N.S.W.	Fifield, N.S.W.	Mount Knowles, N.S.W.	Mount Fairy, N.S.W.	Noumea.	South Africa.	Mossvale District, N.S.W.	Port Kembla.
SiO_2. %	3	3	3	1	6	2	3	5	2	3	96
Fe_2O_3. %	91	90	81	0·2	1	3	1	...	...	30	1
FeO. %	0·5	0	0	...	...	...	...	13	27	0·2	...
MnO. %	0·5	1·8	8	...	...	...	...	...	...	...	...
CaO. %	...	...	...	...	2	57	...	...	...	...	...
$CaCO_3$. %	...	...	...	98	...	...	55	...	...	...	...
Al_2O_3. %	3	3	3	0·3	1	3	0·3	20	24	44	2
MgO. %	...	...	...	...	89	34	...	13	1	...	...
$MgCO_3$. %	...	...	...	0·4	...	...	40	...	...	...	...
Cr_2O_3. %	...	...	...	...	...	...	...	46	45	...	...
TiO_2. %	...	...	...	...	...	...	...	...	...	5	...
P. %	0·05	0·05	0·05	...	...	...	...	...	...	...	...
H_2O. %	2	2	2	...	...	...	...	2	0	16	...

(d) *Raw and Burnt Dolomite.*—Raw dolomite is mined at Mount Fairy, near Goulburn, N.S.W., and crushed at the steelworks to ½-in. maximum. It is used exclusively for slag-line fettling and making up door sills.

Burnt dolomite procured from an independent source is used, alone or mixed with magnesite, for rapid, light repairs to bottoms and unusually impaired slag lines.

(e) *Bauxite.*—During the past two years bauxite has replaced fluorspar as a flux in Kembla open-hearth operations. Obtained in pisolitic form, it is cheap but only about one-third as effective as fluorspar. As a general rule ore is used to break up lime, and the quantity of bauxite used does not exceed 2 lb. per ton of ingots.

Furnace Burden.

Before proceeding to a discussion of furnace design it will be instructive to consider a typical burden sheet for a 230-ton heat of structural steel. The charge is as follows:

Material.	Tons.	Total Metallics. %.
Mill return scrap	35	13·5
Mixer metal	195	75·6
Manganiferous ore (60% Fe) . .	46	10·7
Limestone	11	...
Recarburisers	0·5	0·2

Limestone, 107 lb. per ton of ingots.

The outstanding features of such a furnace burden are the high hot-metal/scrap ratio, the heavy ore charge (448 lb. per ton) and the low flux rate. These furnaces, therefore, are subject to violent and protracted ore boils, resulting in a heavy carry-over of solid particles in the waste-gas stream. It is interesting to note here that with such a practice three of the furnaces have produced ingots at a rate exceeding 21 tons per hr.

Furnace Design.

During the past ten years improvements in design have been effected that have enabled large stationary furnaces to be built, which carry such burdens continuously for campaigns exceeding 36 weeks. High production rates are maintained with low repair, maintenance and rebuilding costs.

Compared with the first unit, which commenced to operate in 1931, the following features are incorporated in the construction of furnaces *F* and *G*, designed and built since 1939:

(*a*) Since the melting shop main building columns are on 90-ft. centres, bath areas could not be increased substantially without constricting critical areas necessary to generous end design. Hence, the average bath depths have been increased, to enable furnaces to tap larger heats.

Despite adverse criticism in some quarters abroad, the

so-called deep-bath furnaces are an outstanding success in Australia and are noted for high tonnage rates and low costs.

(*b*) Modifications to furnace lines over the melting chamber, throat and ends have been effected to maintain a silica-roof life of 350 heats without retarding the steelmaking rate.

(*c*) A generous treatment of critical areas throughout the furnace and ancillaries has been adopted to keep unit gas velocities within desired limits. This has had the desired effect of maintaining keener-working furnaces and reducing costs of refractories.

(*d*) Basic ends were constructed to inhibit the fluxing of refractories and minimise slag-pocket accumulations.

(*e*) Suspended rigid roofs balanced for even distribution of stress were built.

(*f*) Two slag notches were provided to take care of flush slag.

(*g*) Slag-pocket design was improved and greatly increased capacities were introduced to enable furnaces to operate for long periods without stopping to remove accumulations.

(*h*) Regenerator design was developed to obtain satisfactory gas distribution and provide heating surface capacities commensurate with hourly tonnage rates. Stack temperatures were lowered and fuel figures improved.

(*i*) The two latest furnaces *F* and *G* (Figs. 4 and 5) were built with single slag-pockets and regenerators. It is believed that the span of the regenerator arches approaches the largest yet tried. They are in excellent shape after two years' service.

(*j*) Modifications of checker-tile design and openings have been applied to facilitate routine cleaning and promote long-term maintenance of draught.

(*k*) Cleaning tunnels have been constructed beneath slag-pockets, giving access to the regenerator runner wicket through which dust is either removed or blown towards the stack.

(*l*) Runners beneath regenerators have been made much larger.

(*m*) The flues between regenerators, valves and main stack flue are not filled in, and remain accessible. Flues and valves are placed in a well illuminated chamber covered at valve-pit level with floor plate. Numerous wickets provide quick access to runners and valve seats.

(*n*) The large furnaces have been equipped with bifurcated tapping spouts, splitting the heats into two ladles.

Results undoubtedly justify the efforts that Kembla has directed to the establishment of a balanced furnace.

Table IV. shows the development in design during the past ten years. It is evident that the producer-gas furnaces have not received as much attention as the fixed-fuel[1] furnaces, but a

[1] "Fixed" fuel is fired at high pressure; low-B.Th.U. fuel at low pressure.

TABLE IV.—*Progress in Furnace Design above Charging Floor. Period* 1931–41.

Furnace:	*B.*	*B.*	*C.*	*A.*	*A.*	*F.*	*G.*
Year Built:	1931.	1931.	1933.	1939.	1939.	1940.	1941.
Figures taken:	1931.	1941.	1941.	As built.	1941.	1941.	1941.
Primary Fuel:	Producer Gas and Coke-Oven Gas.			Tar and Coke-Oven Gas.			
Critical areas.							
Furnace laboratory centre-line	97 sq. ft.	118 sq. ft.	113 sq. ft.	127·5 sq. ft.	131 sq. ft.	127·5 sq. ft.	150 sq. ft.
At knuckles	50 ,,	54 ,,	55 ,,	48 ,,	71 ,,	82 ,,	72 ,,
Gas port area	6 ,,	4·2 ,,	4·2 ,,	...	...	...	...
Area over bridge wall	64 ,,	88 ,,	77 ,,	70 ,,	84 ,,	94 ,,	98 ,,
Total area:							
Air uptakes	38 ,,	68 ,,	53 ,,	69·5 ,,	77 ,,	94 ,,	80 ,,
Gas uptakes	12·7 ,,	14·4 ,,	12 ,,	...	...	...	...
Longitudinal dimensions.							
End steel to air uptakes	2 ft. 10 in.	3 ft. 3 in.	2 ft. 10 in.	3 ft. 3 in.	3 ft. 3 in.	3 ft. 3 in.	3 ft. 3 in.
Length:							
Air uptakes	5 ft. 6 in.	6 ft. 0 in.	6 ft. 0 in.	6 ft. 0 in.	7 ft. 0 in.	7 ft. 3 in.	6 ft. 0 in.
Throat	10 ft. 0 in.	5 ft. 0 in.	9 ft. 3 in.	7 ft. 0 in.	8 ft. 9 in.	7 ft. 0 in.	5 ft. 9 in.
Bath	43 ft. 0 in.	43 ft. 0 in.	43 ft. 0 in.	45 ft. 0 in.	45 ft. 0 in.	45 ft. 0 in.	47 ft. 6 in.
Overall furnace	79 ft. 8 in.	79 ft. 8 in.	79 ft. 8 in.	79 ft. 8 in.	79 ft. 8 in.	79 ft. 8 in.	79 ft. 8 in.
Elevations of roof from foreplate.							
(1) Centre-line hearth to skew	4 ft. 4 in.	5 ft. 6 in.	5 ft. 3 in.	5 ft. 1 in.	5 ft. 8 in.	5 ft. 9 in.	5 ft. 9 in.
(2) Centre-line hearth to max. rise of roof	6 ft. 7 in.	7 ft. 9 in.	7 ft. 9 in.	8 ft. 1 in.	8 ft. 8 in.	8 ft. 7 in.	9 ft. 2 in.
						11½ in.	
(3) At knuckles to skew	4 ft. 0 in.	4 ft. 6 in.	4 ft. 4 in.	3 ft. 7 in.	5 ft. 2 in.	4 ft. 9 in.	5 ft. 2 in.
(4) At knuckles to max. rise	5 ft. 6 in.	5 ft. 2 in.	5 ft. 10 in.	6 ft. 4 in.	7 ft. 2 in.	6 ft. 9 in.	6 ft. 8 in.
(5) Ends:							
(*a*) To skew	8 ft. 8 in.	8 ft. 10 in.	8 ft. 9 in.	8 ft. 6 in.	8 ft. 9 in.	8 ft. 9 in.	8 ft. 9 in.
(*b*) To max. rise	10 ft. 4 in.	10 ft. 10 in.	10 ft. 9 in.	10 ft. 6 in.	10 ft. 9 in.	10 ft. 9 in.	10 ft. 9 in.
(6) Elevation main roof minus that at knuckles	4 in.	1 ft. 6 in.	11 in.	9 in.	6 in.	10 in.	7 in.
(7) Elevation end roof minus that at knuckle	4 ft. 8 in.	4 ft. 10 in.	4 ft. 9 in.	4 ft. 2 in.	3 ft. 7 in.	...	3 ft. 7 in.
Back-wall	Straight.	Straight.	Straight.	Sloping.	Sloping.	Sloping.	Sloping.
Monkeys, width:							
(*a*) Top	11 ft. 6 in.	8 ft. 10 in.	9 ft. 0 in.	10 ft. 0 in.	11 ft. 6 in.	11 ft. 3 in.	10 ft. 0 in.
(*b*) Bottom	11 ft. 6 in.	10 ft. 4 in.	11 ft. 0 in.	12 ft. 0 in.	13 ft. 6 in.	13 ft. 3 in.	12 ft. 6 in.
Length, roof:							
Hood	8 ft. 7 in.	11 ft. 6 in.	...	8 ft. 6 in.	9 ft. 0 in.	8 ft. 6 in.	8 ft. 7 in.
Hood slope	7 ft. 0 in.	5 ft. 0 in.	...	5 ft. 9 in.	6 ft. 0 in.	5 ft. 9 in.	4 ft. 9 in.
Knuckle	...	2 ft. 0 in.	...	2 ft. 6 in.	2 ft. 6 in.	2 ft. 6 in.	2 ft. 6 in.
Main roof slope	7 ft. 0 in.	5 ft. 9 in.	...	6 ft. 9 in.	5 ft. 6 in.	6 ft. 9 in.	7 ft. 9 in.
Main roof	29 ft. 0 in.	27 ft. 6 in.	...	29 ft. 0 in.	30 ft. 0 in.	29 ft. 0 in.	29 ft. 0 in.
Port nose to centre knuckle	4 ft. 6 in.	8 ft. 3 in.	7 ft. 5 in.	7 ft. 0 in.	8 ft. 9 in.	6 ft. 9 in.	6 ft. 3 in.

TABLE V.—*Regenerator Details.*

Furnace:	*B.*		*F.*	*G.*
Date:	July, 1941.		July, 1941.	June, 1941.
Normal Fuel:	Producer Gas.		Tar and Coke-Oven Gas.	Tar and Coke-Oven Gas.
Arbitrary Rating:	14 tons per hr.		17 tons per hr.	18 tons per hr.
	Air.	Gas.		
Regenerator:				
Length	28 ft. 0 in.	28 ft. 0 in.	28 ft. 0 in.	31 ft. 3 in.
Width	12 ft. 6 in.	8 ft. 3 in.	21 ft. 0 in.	21 ft. 0 in.
Height, checkers above rider tile	11 ft. 0 in. to 12 ft. 0 in. stepped.	11 ft. 0 in. to 12 ft. 0 in. stepped.	12 ft. 0 in.	13 ft. 6 in.
Checker work:				
Volume	3880 cu. ft.	2580 cu. ft.	7060 cu. ft.	8860 cu. ft.
Type	Box flue.	Box flue.	Box flue.	Box flue.
Tile	13 in. × 6 in. × 2 in.	13 in. × 6 in. × 2 in.	Beam tile 13½ in. × 6 in. × 3 in.	Beam tile 13½ in. × 6 in. × 4 in.
Hole, size	5½ in. × 5½ in.	5½ in. × 5½ in.	10½ in. × 4 in.	10½ in. × 6 in.
Total available heating surface	18,000 sq. ft.	12,000 sq. ft.	33,930 sq. ft.	36,760 sq. ft.
Size ratio air to gas	1·5 : 1·0		...	...
Combined volume	6460 cu. ft.		7060 cu. ft.	8860 cu. ft.
Heating surface per ton per hour (one end only)	2140 sq. ft.		1995 sq. ft.	2040 sq. ft.
Normal exit flue temp.	1400–1500° F.		1000–1050° F.	1000–1050° F.

campaign is now proceeding in their favour. Kembla *B* furnace was redesigned in July, 1941, to tap 200-ton heats, and it is the first gas-fired furnace in Australia to operate with fully basic ends, *i.e.*, cold walls, end panels and midfeathers of 100% basic construction down to the slag-pocket arches. As this paper is being written, *E* furnace has commenced production with basic ends. The size of heat tapped remains the same, *viz.*, 160 tons, hence sufficient data will be collected during the next twelve months to enable a sound forward policy to be formulated for the improvement of gas-fired furnaces.

To complete the general perspective of the salient features of Kembla furnace design, Tables V. and VI. show details of regenera-

TABLE VI.—*Details of Slag Pockets.*

Furnace: Date: Normal Fuel:	*B.* 1941. Producer Gas and Coke-Oven Gas.		*G.* 1941. Tar and Coke-Oven Gas.
Slag pockets:	Air.	Gas.	
Average length	27 ft. 4 in.	30 ft. 4 in.	26 ft. 6 in.
Average height	6 ft. 3 in.	6 ft. 3 in.	9 ft. 3 in.
Average width	5 ft. 0 in.	5 ft. 0 in.	13 ft. 6 in.
Total volume	1900 cu. ft.		3250 cu. ft.
Slag-pocket deposit:			
Total per ton of ingots	13 lb.		15 lb.
Specific gravity	6·5		5·0
Weight per cu. ft.	406·25 lb.		312·5 lb.
Campaign tonnage before encroachment on free flow of gases	118,000 tons.		136,000 tons.

tors and slag pockets. Plant policy for regenerators is to provide up to 2,000 sq. ft. of heating surface per hour per ton of steel produced on fixed-fuel furnaces, and 3,000 sq. ft. on producer-gas furnaces. It is obvious that the gas furnaces at present are but moderately provided for, compared with contemporary furnaces abroad. Ample provision would involve total reconstruction, which conceivably might be undertaken in due course. The regenerator outlet temperatures of the tar furnaces are normal for units of their type, whereas the high figures of the gas furnaces indicate high unit gas velocities and insufficient checker capacity.

Table VI. emphasises the generous treatment of slag-pocket design in recent installations.

Furnace Construction.

Figs. 2, 3, 4 and 5 show the general arrangement of the most recent Kembla open-hearth furnace. The complete superstructure of the furnace is rigidly bound together. Buckstays around the

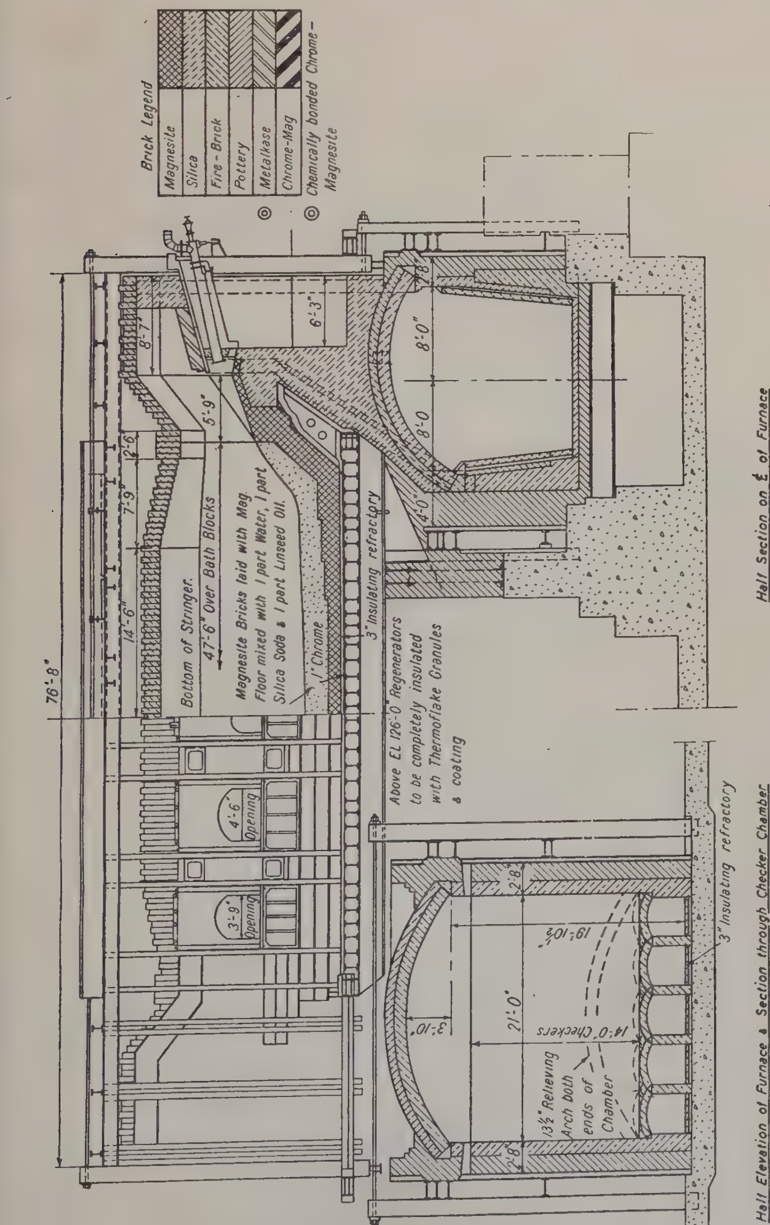


FIG. 2.—240-Ton Fixed-Fuel Open-Hearth Furnace.

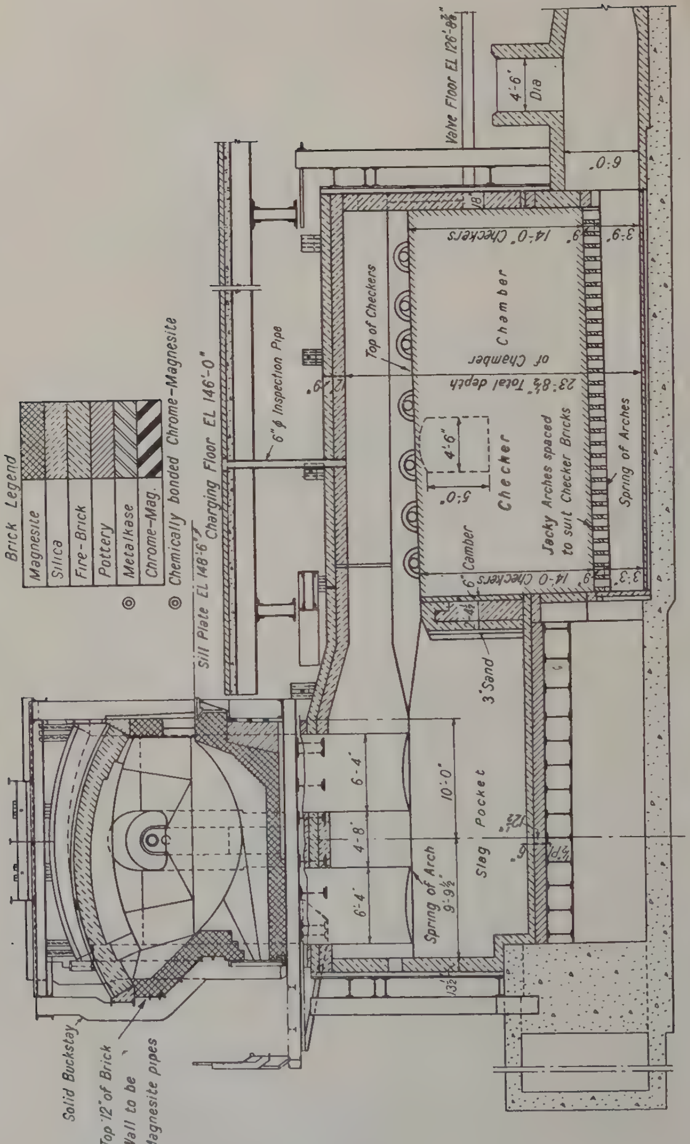


FIG. 3.—240-Ton Furnace. Sections on centre-lines of the furnace and of the slag pocket and checker chamber.

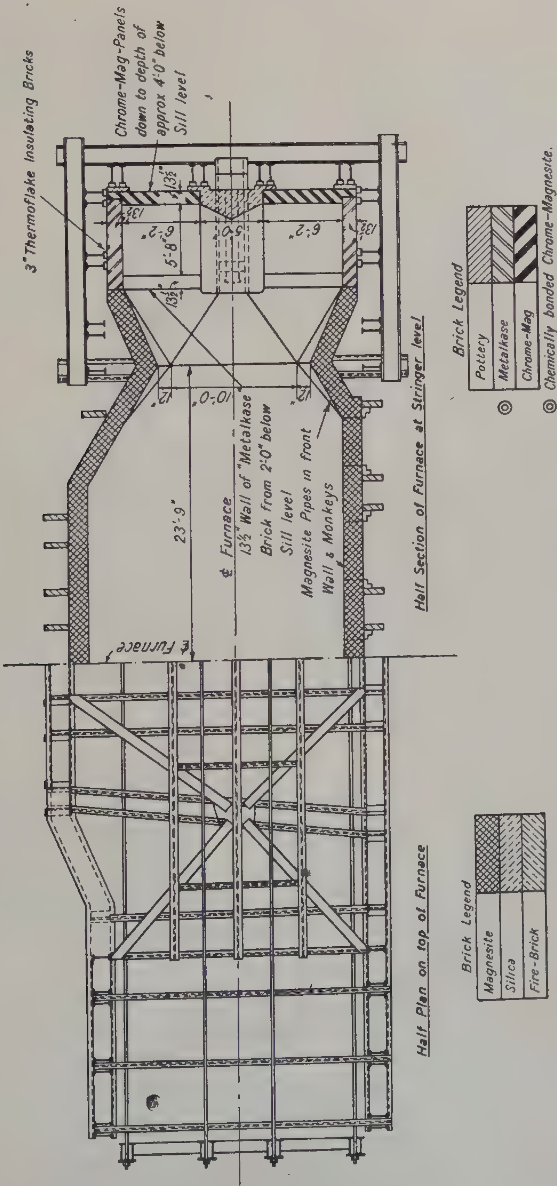


FIG. 4.—240-Ton Furnace. Half plan on top of furnace, and half section of furnace at stringer level.

hearth proper are rolled 18 in. × 6-in. solid slabs, and 12 in. × 6-in. rolled-steel joists are used on the ends.

Fig. 2 illustrates the method adopted for rigid roof ties. In common with all furnaces in the plant, the skewback channels are made up of specially rolled heavy-section semi-finished 24 in. × $7\frac{1}{2}$-in. beams with both flanges on one side oxy-cut away. The skew

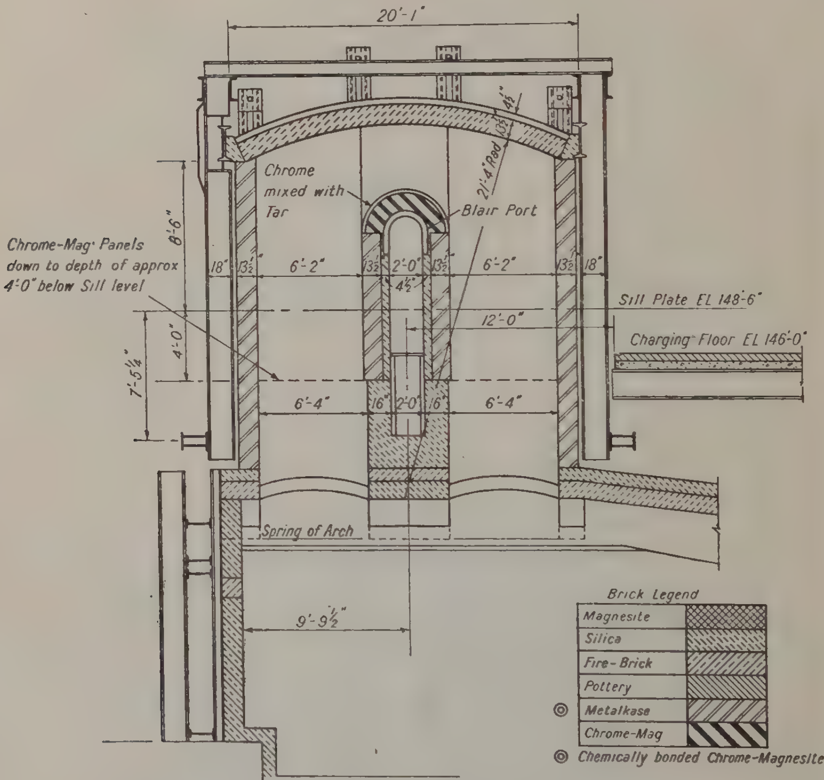


FIG. 5.—240-Ton Furnace. Section through the uptakes.

channels are swung from the roof superstructure by $1\frac{1}{4}$-in. dia. bolts. A 1-in. water-cooling pipe is laid within the skew along the bottom flange, and extends from knuckle to knuckle along the front and back wall. These pipes are standard construction throughout the shop, and, by the protection afforded to the skew channel in the later stages of a campaign, they undoubtedly prolong the roof life.

The roof span is 20 ft. 1 in. over the furnace ends and 23 ft. 1 in. over the sloping back wall at the centre-line of the furnace.

The roof construction is alternate row ribbed, and of silica brick varying in thickness from 24 in. to 16 in. from the skew towards the crown, as follows:

Eleven rows	24 in. and 20 in.
Four rows	20 in. and 18 in.
Balance of crown	18 in. and 16 in.

This type of roof averages about 350 heats and has been found the best suited to rapid and effective hot repair. The elevation of the roof at the skewback channel above foreplate level is 5 ft. 9 in. at the tap-hole and 5 ft. 2 in. at the knuckles.

The sloping back wall is built of magnesite bricks encased in steel plate to within 18 in. of the skew. Chrome-magnesite pipes are then laid to the skew, and this work can be hot-repaired during charging operations if necessary.

Front walls are constructed entirely of chrome-magnesite pipes, with water-cooled frames and doors as standard equipment. Experiments with monolithic door linings are encouraging and their extensive use in the future is indicated.

Door arches are of 1-in. dia. chrome-magnesite pipes supported by $1\frac{1}{4}$-in. water-cooled coils laid behind the door frames.

Fig. 11 is a view of *G* furnace from the charging side. Door openings comprise a centre observation door 3 ft. wide, two inside charging doors 4 ft. 6 in., and two end doors 3 ft. 9 in. wide. Such an arrangement is satisfactory for furnaces operating on low-scrap practice. The two 4 ft. 6-in. openings allow the furnace to be quickly charged, and the small centre door affords protection to the crew during routine tapping-hole operations.

(a) *Hearth Construction.*

The nominal hearth dimensions are 47 ft. 6 in. × 17 ft., and the bottom is formed in a pan of 1-in. plate reinforced by arc-welded cover-strips. The support is very strong and is made up of longitudinal 24 in. × $7\frac{1}{2}$-in. beams on the concrete foundations with cross beams of 12 in. × 8-in. section immediately beneath the pan. The hearth chills are fabricated and air-cooled.

In Australian steelworks there has been little departure from the orthodox in the installation of bottoms. There are probably two outstanding reasons for this. Excellent results have been obtained for many years with sintered-magnesite bottoms. The oldest Kembla hearth is more than ten years old and still giving good service. Again, Australian plants are far distant from the large steel-producing countries and are therefore cut off from the supplies of proprietary basic bottom-making materials so readily available to operators abroad.

The installation of *G* furnace bottom commenced by covering the pan rivets with crushed chrome ore. A 3-in. course of diatomaceous-earth insulating bricks was then laid. This was followed by $16\frac{1}{2}$ in.

of magnesite bricks, four courses on the flat and one on edge. These bricks were laid up with flour magnesite, linseed oil and water. The expansion allowed in the bottom and bank masonry was $\frac{1}{8}$ in. every 18 in. laterally and longitudinally. Banks were constructed of magnesite brick over first-class fireclay brick, which began at a point 24 in. inwards from the steel of the hearth casing and then battered upwards. An area of 96 sq. ft. around the tapping hole was laid entirely in magnesite.

The working bottom was sintered-in with a mixture of 6 parts of crushed local magnesite and 1 part of basic slag. Continuous samples were taken at intervals to check the progress of this operation. Burning-in a bottom takes about eight days from firing the furnace to steel production and 90 tons of magnesite are required. Prior to charging, the bottom is washed out with slag and "set back" for 8 hr.

The composition of *G* furnace bottom was:

SiO_2.	FeO.	Fe_2O_3.	Al_2O_3.	CaO.	MgO.	P_2O_5.
7·4%	1·5%	5·0%	2·4%	9·0%	73·5%	0·2%

Softening point, 1850° C.

The total refractory thickness of this bottom is 36 in., made up as follows:

Chrome ore on pan . . .	$\frac{1}{2}$ in.
Insulation	3 in.
Magnesite brick	$16\frac{1}{2}$ in.
Sintered magnesite . . .	16 in.

(b) *Furnace Ends.*

The ends of *G* furnace received careful attention during design and construction. Reference to Table IV. will supply the outstanding features. The main objects of the design were, first, to balance the ends, if possible to restrict the carry-over and keep the waste-gas velocity low, and, secondly, to house and protect the tar and coke-oven gas burner without encroaching on the desired free area between the bridge wall and roof.

The dog-box construction carrying the modified water-cooled protection port is shown in Fig. 12. This port is 10 ft. long overall and 2 ft. 6 in. in width, and is simply an arched tank of soft-steel plate with a 3-in. layer of circulating water. Special pipes are welded into the nose of the port for routine flushing and the prevention of hot spot.

The port houses the combination tar and coke-oven-gas burner previously described, and in this instance the nozzle sizes are for tar $\frac{3}{4}$ in. dia. and gas $4\frac{3}{4}$ in. The burner is swivelled at the back so that the elevation and direction of the flame can be altered at will.

The end-panel and cold-wall construction is entirely basic down to the slag-pocket arches. Chrome-magnesite pipes $13\frac{1}{2}$ in. long are used. An interesting feature of design is the excellent method used

to support the great weight of the basic material and prevent the crushing of the silica beneath. At 3-ft. intervals T-bar cut from 20-in. rolled steel joist is welded horizontally to the buckstays to form trays upon which the refractory pipes are laid. Suitable expansion allowances are made at each level and no difficulties occur when heating up.

The downtake arches are of silica; this eliminates the old "jack" arches, affords greater free area for gas flow, and reduces repairs and maintenance.

(c) *Slag Pockets.*

There are two features of pocket design worthy of mention, the first being the generous capacity allowed. Details are given in Table VI. *G* furnace can operate for upwards of 580 heats, produced in a campaign exceeding one year, before pocket accumulation will interfere seriously with the free flow of furnace gases through the system.

Slag-pocket floors are heavily sanded and false silica walls without cavities are laid on the sides.

G furnace slag pockets are built on a 12½-in. reinforced-concrete pad supported by 24 in. × 7½-in. rolled steel joists, which form the ceiling of a chamber 26 ft. 6 in. long × 16 ft. 9 in. wide × 6 ft. high. This chamber, entered by stairways at the ends of the furnace, gives access to the regenerator runners for blowing and cleaning. A 20-in. cool-air pipe laid longitudinally through the main furnace foundations from end to end keeps the atmosphere cool and comfortable to work in. Regenerator runners are therefore examined at intervals during operation, and cleaning proceeds as required.

(d) *Regenerators.*

The 21-ft. regenerator arches installed on *G* furnace have had almost two years' trial on furnace *F*. They are in excellent shape and condition. These arches are of fireclay brick. The fantail arches of silica have been streamlined into the regenerator chambers with due regard for even waste-gas distribution over the checkers. Details of regenerator practice are shown in Table V.

(e) *Valves and Stack.*

The valves are straight-line and water-cooled with water-cooled seats angled in the flues to the stack. Fig. 13 shows *G* furnace valve pit. The flow of gases is reversed in 3 sec.

The air valves are of cast-iron mushroom type, completely enclosed. Air for combustion is delivered by a fan of 23,000 cu. ft. per min. capacity at 3 in. water gauge, driven by a rheostat-controlled variable-speed motor.

The main stack flue, 8 ft. in dia., is fully enclosed in a steel tube set in concrete and leads beneath the stockyard to a firebrick-lined

riveted steel stack 7 ft. in dia. and 200 ft. high. The normal available operating draught at the base of the stack is 2 in. water gauge.

(f) *Insulation.*

The insulation of open-hearth furnaces has not progressed very far in Australia, possibly because published reports are rather arbitrary and conflicting, but the value of an air-tight furnace is well appreciated, and insulation is used extensively beneath charging-floor levels. *G* furnace regenerators and fantails are coated with 2 in. of mica-asbestos granules.

(g) *Cooling Water.*

The furnace is cooled with sea water delivered from a main which encircles the furnace roof superstructure. Waste water is taken to the ends above roof level also. This system is well designed and completely safe.

Instrumentation.

All Kembla furnaces are equipped with well designed instrument panels, which of course are invaluable to the operators. A typical control board for tar- and coke-oven-gas-fired furnaces is fitted with the following instruments and controls:

(1) Roof temperature control, indicating and recording.
(2) Tar flowmeter, indicating and recording.
(3) Tar pressure regulator, indicating and recording.
(4) Tar temperature recorder.
(5) Coke-oven-gas flowmeter, indicating and recording.
(6) Air flowmeter, indicating and recording.
(7) Steam pressure regulator, indicating and recording.
(8) Steam temperature recorder.
(9) Furnace draught control.
(10) Switches for remote-control tar valves.
(11) Forced-draught fan speed control.
(12) Reversing valve switch.
(13) Door-operating switches.

The tar reversing manifold is placed conveniently in front of the panels. All furnaces are reversed by motor in 3 sec. after throwing the switch. Reversals are made on time intervals taken from two large electric master clocks with illuminated dials.

The relative merits of the various aids to furnace control have been freely discussed by furnace operators everywhere. At this plant it is believed that automatic draught control of approved design, when properly used, is most valuable. Roof temperature control is most desirable, but carbon roof blocks need constant care and rayo tubes require daily calibration for the control to give results. It is apparent that the major proportion of the responsibility for roof care still remains with the first helper.

At least two items of control should receive more attention from

operators, namely, reversal by temperature differential, and some form of combustion control.

Often in the routine of charging-floor operations a helper forgets, or is unable, to reverse his furnace on time, with resultant damage to furnace downtakes and check tile, and disturbance of the working balance of the furnace. Fully automatic reversing by temperature differential prevents such occurrences and encourages the helper to take more interest in the actual progress of the heat.

At Port Kembla all furnaces are operated with forced draught and an effort is made to run with 30–40% of excess air, showing 2–4% of oxygen in the downtake gases. However, the only method of control is to meter the air for varying fuel rates and to check the waste gases frequently by Orsat tests. Some very good results are obtained in this way, but the liability to error is considerable. Perhaps the time is not far distant when combustion will be continuously checked by an oxygen recorder of approved design inserted in the downtakes at both ends.

Refractories.

Australian steelmakers as well as those of England and the United States of America are giving much attention to open-hearth refractories. Possibly the foremost future saving in costs will be derived from the use of improved refractories. The all-basic furnace is the universal objective, and there can be little doubt that the lowest open-hearth operating costs will not be realised until the all-basic furnace appears. To-day, five of Port Kembla's seven furnaces are all-basic except for the roofs and downtake arches. Campaigns close when roof structures become unstable and dangerous. When silica roofs are replaced by basic arches constructed with proven high-strength thermally satisfactory basic brick, campaigns of 400 heats may lengthen to possibly 1,000. The balance of present design then will be upset and weaknesses will show up at other sections of the structure. With the previously described features of furnace design it is believed that some of the Kembla units could use basic roofs to advantage now. A full campaign would run up to two years, divided into two non-stop periods with a short cleaning and patching time between. Steelmaking rates would be 10–15% faster and overall repairs and maintenance costs appreciably lower.

Silica brick of the following composition is used in roof construction :

SiO_2.	Fe_2O_3.	Al_2O_3.	TiO_2.	CaO.	Specific Gravity.	Fusion Point.	Porosity.
95%	1%	0·6%	0·1%	3%	2·34	1740° C.	22%

The physical properties of the brick are well up to accepted standards but not yet equal to those of the " super silica " brick available in some places abroad.

Roof life varies with the type of fuel fired, and on the present basis of comparison averages 370 heats on producer-gas-fired units. The traditional method of recording roof performance by the number of heats carried is wrong. Some plants during a compaign entirely replace a roof in running and mid-campaign repairs, and credit the service to one roof. This procedure, of course, is misleading, since the roof cost must greatly exceed the expenditure on the original roof. Further, roof thicknesses vary from plant to plant, and it is obvious that a run of 300 heats with a 16-in. roof at one plant is a better performance than a run of the same number of heats with a 22-in. roof at another plant. Steelmakers quoting furnace performance should therefore refer to roof life in terms of weight of silica refractory consumed per ton of ingot.

(a) *Front Walls, Back Walls and Bulkheads.*

For some years past a highly efficient domestic refractory has given good results in the construction of front walls, back walls, air and gas bulkheads, cold walls and air-cooled monkey walls. Australia has not progressed as rapidly as the U.S.A. and England in the development of basic refractories, and supplies of local basic bricks of specified quality are not available. However, chrome-magnesite pipes made at the open-hearth have run for 800 heats in the air bulkheads of a 230-ton tar-fired furnace without repair. This wall was 18 in. thick. Old boiler tube of 1–4-in. dia. is oxy-cut to the desired length and filled with 50% chromite, $\frac{1}{4}$ in. maximum, and 50% dead-burned magnesite, $\frac{1}{8}$ in. maximum. The bond is a 4% solution of 1·7 sp. gr. waterglass and the materials are mixed in a concrete mixer. The packed pipes are air-dried for at least three months and finally dried in a skip on a furnace roof before use. Masonry built of pipe is bonded with the same mixture. Rarely before 150 heats is hot repair to a front wall or straight back wall required, and up to 200 heats have been made before patching. The average front-wall life is 175 heats.

(b) *Midfeather Walls.*

Recently an all-basic-end gas furnace was put into service with midfeathers constructed of hard-burned chrome-magnesite brick. After 16 weeks' operation these walls are still perfectly gas-tight and it is hoped that midfeather leaks at last have been overcome. From experience at Kembla with basic ends, it is not difficult to anticipate an early release from the exasperating task of removing those big masses of pocket slag that too often have kept furnaces off the line for days beyond the normal repair periods. These dense slags have been replaced by soft easily removable accumulations on tar units; it is hoped that a similar result will be obtained in the gas-fired furnaces.

(c) *Regenerators and Slag Pockets.*

The slag-pocket and fantail arches are of silica brick construction, but regenerator arches are of standard fireclay bricks containing :

SiO_2.	Fe_2O_3.	Al_2O_3.	TiO_2.	CaO.	MgO.
71%	2%	24%	1%	0·4%	0·5%

Checker tiles of similar material are of two standard sizes, 15 in. × 6 in. × 2 in. and 13 in. × 6 in. × 2 in., laid in uniform box flues, one pass only. This plant has not experimented with tiles of variegated design or multiple-pass checkers. Careful attention to cleaning, with trained crews working to established weekly schedules, and the education of first helpers to prevent overheating has ensured comparative freedom from checker troubles. Checkers are cleaned down with compressed air, at 100 lb. per sq. in. pressure, through slotted cast-iron apertures along and across. Furnace crews can examine checkers with an observation pipe extending through the charging floor into the dome of the regenerator arch.

It is difficult to assess an average checker life. Replacements are made, depending upon the condition, but usually the top four or five rows are removed after each campaign, the remainder being good for two campaigns.

Furnace Performance.

The long-term performance of the modern Kembla furnaces has been encouraging. The details of the first campaign of *F* furnace, completed in January, 1940, are :

Days operated	246 (17/1/40 to 13/11/40)
Heats	400
Tons per heat	203
Gross tons	81,362
Tonnage per week	2,315
B.Th.U. per ton of ingots	3,658,500

Charge Composition.

	Tons.	%.
Mixed and direct metal	62,208	66·8
Cold iron	5,717	6·1
Steel scrap	16,462	17·7
Iron ore (60% Fe)	8,656	9·4
Limestone	3,343	

The record monthly production during this campaign was made in March, 1940, when the furnace produced 11,311 tons of ingots at a rate of 2,862,000 B.Th.U. per ton.

The initial campaign of the latest Kembla furnace, *G*, is still in progress, but the mid-November, 1941, details were :

Days operated	150
Heats	222
Tons per heat	233
Gross tons	51,789
Tonnage per week	2,415
B.Th.U. per ton of ingots	3,672,000

For July, 1941, *G* furnace made 11,627 gross tons of ingots at a rate of 3,442,000 B.Th.U. per ton, charging 15% of steel scrap.

Operations.

(a) *Stockyard.*

The Port Kembla stockyard lies parallel to the furnace building. A standard-gauge railway track runs through the yard and there are short shunting spurs at each end. With the exception of ore, all charge components are marshalled within the yard by the two 15-ton combination magnet and cradle cranes. Since the plant normally operates on a 15% scrap burden all scrap is mill return. Scrap returns are organised so that about 90% arrives at the yard ready for charging. Rolling stock for transport comprises light, flat-topped wagons which carry one charging crate with three pans. Each fabricated charging pan has a capacity of 36 cu. ft. and holds 1–3 tons of scrap, or $2\frac{1}{2}$ tons of ore or $1\frac{1}{2}$ tons of limestone.

Provision is made in the scrap-yard for the isolation of alloy scrap, in a coloured area.

When preparing charges the cranes usually work in collaboration, one loading with the magnet and the other elevating the loaded crates to the two 25-ton weighbridges at charging-floor level. After weighing, the crates are set down on the charging bench opposite the furnace.

A series of large bins is provided for phosphate rock, sea sand, bauxite and fluorspar, and these are hand-loaded into pans as required.

As in all plants, the scrap is proportioned according to type, so that furnaces receive a balanced charge of light and heavy scrap.

(b) *Bottom Maintenance.*

The quality, quantity and yield of steel made in any open-hearth shop is largely dependent upon bank and bottom maintenance. Loose dirty bottoms tap metallurgically dirty steels, and bottoms which drain badly can lower the overall plant yield by more than 1%. Deoxidation practices are also directly influenced. The prevalent custom of allowing cost and availability to govern the choice of materials used for repairs is not commendable when it is possible for the cost of extra time lost by bank and bottom repairs through using cheap refractories to exceed the extra cost of better materials.

While prepared dolomitic refractories as used abroad are not available to Australian operators, local materials are used to meet requirements.

Severe bottom damage is repaired by sintering-in dry calcined magnesite with 10–15% of basic slag, a proportion of burnt dolomite occasionally being added to save time. Localised less severe damage is often repaired with wet calcined magnesite applied as a partially hydrated pug, and charging can commence almost at once

without danger. Severe cutting along the slag-line is repaired with burnt dolomite, but routine fettling is done with crushed raw dolomite. For best results the dolomite should be small and uniform in size. Arbitrary opinions are expressed concerning the value of raw dolomite. When applied it must be calcined and sintered into place before the hot-metal addition. If fixation does not occur, the dolomite lifts and interferes with the flush slag. That portion which remains in the furnace increases the finishing-slag volume, makes slag control difficult and slows down production, this perverse condition continuing from heat to heat. At times 6 in. or more of the bank comes away. Moreover, the furnace cannot remain idle for any length of time without serious deterioration of the banks. The best fettling refractory would appear to be a self-bonding weatherproof ferruginous dolomitic material in uniformly sized acicular particles of high softening point.

The use of the fettling machine at Kembla undoubtedly saves time. Generally bottoms tend to become high and banks to toe out, and periodical wash-outs are essential. The oldest bottom here is still giving satisfactory service after eleven years.

(c) *Charging.*

Charging schedules covering all kinds of conditions have been studied at Port Kembla over long periods. It is essential for the furnaces to be charged carefully and rapidly. If careless machine operators dump heavy scrap and limestone in piles near the ends, hours are added to the melting time and damage is done to door jambs. The overhead charging machines, with their freedom of movement, give excellent service. The following is the charging time objective on a standard heat for a 230-ton fixed-fuel furnace :

Begin charging		0 hr.
Scrap	35 tons.	
Manganiferous ore	46 tons.	
Limestone	11 tons.	
Finish charging solids at		1 hr. 30 min.
1st ladle hot metal		3 hr. 45 min.
2nd ,, ,,		4 hr. 15 min.
3rd ,, ,,		4 hr. 45 min.

Total charging time, $4\frac{3}{4}$ hr.

Fig. 6 shows a portion of an actual time study of charging and filling-up times. Correlated with charge composition and hourly production rates, such graphs, recorded daily, are invaluable for the rapid analysis of shop operations.

As a general rule, one-third of the scrap is spread over the bottom, followed by the limestone, then the ore, and finally the balance of the scrap. The timing of the hot-metal addition is of great importance. If the furnace is filled too soon the heat is delayed, insufficient flush slag is taken and the finishing slag is too

siliceous. Should filling be delayed, violent reactions ensue and floor spills occur, yield is lost and the carbon contents of the heats at melting are irregular. For satisfactory routine operation and consistent quality, furnaces must take hot metal on time. The procedure at Kembla is to pour the iron from the 1200-ton mixer to the transfer ladle, run the car to the weighbridge 40 ft. away, and hoist directly to the floor with the 100-ton crane. The following is a typical time cycle for hot-metal additions:

Pouring from mixer, weighing, hoisting, transferring .	14 min.
Pouring into furnace	5 min.
Returning ladle to mixer, lowering to bridge, and re-taring	8 min.
Total	27 min.

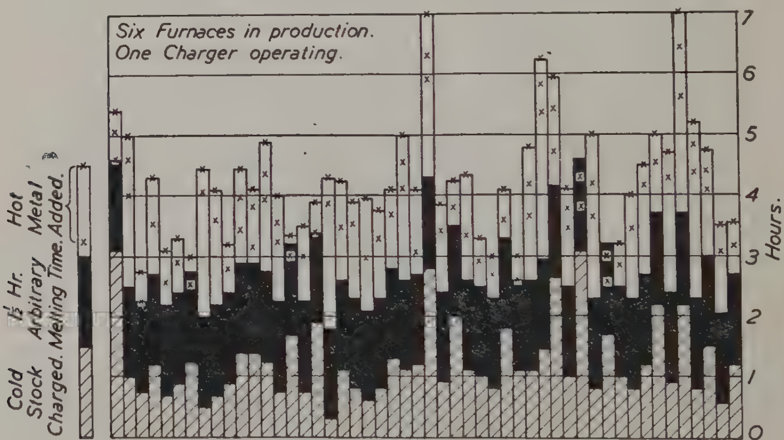


FIG. 6.—Charging Times for Fifty Consecutive Heats.

Scrap.—The average scrap charge is 13–16% of the total metallics and consists almost entirely of mill returns. On special grades of alloy steels heats are charged with up to 50% of scrap, mainly with a view to alloy recovery and controlling expensive alloy additions within narrow limits.

Cold Pig Iron.—On the rare occasions when cold iron is charged it is placed on top of the scrap.

Hot Metal.—In order to obtain smooth operation, accurate melts and consistent quality, it is imperative that the proportion of silicon in the hot metal should be known to the melters beforehand. In addition to a calculated figure obtained from the mixer throughout, two mixer-iron analyses are made on each shift. The melter adjusts the order burden accordingly. The desired basic iron composition is as follows:

Silicon.	Sulphur.	Phosphorus.	Manganese.
0·8–1·0%	0·04% max.	0·10% max.	2·3–3·0%.

The average charging temperature of the mixer metal is 2300° F. Fig. 7 shows the range of variation of silicon content of the mixer metal compared with the sequence of silicon contents in the iron from the blast-furnaces.

(d) *Melting.*

Charges are melted down as rapidly as possible and arranged to melt at 0·4–0·6% higher than the final carbon desired, so that 1–1½% of manganiferous iron ore can be used. The average fuel input per hour varies between 55×10^6 and 65×10^6 B.Th.U., depending upon conditions. Heats are kept hot throughout and the temperature for

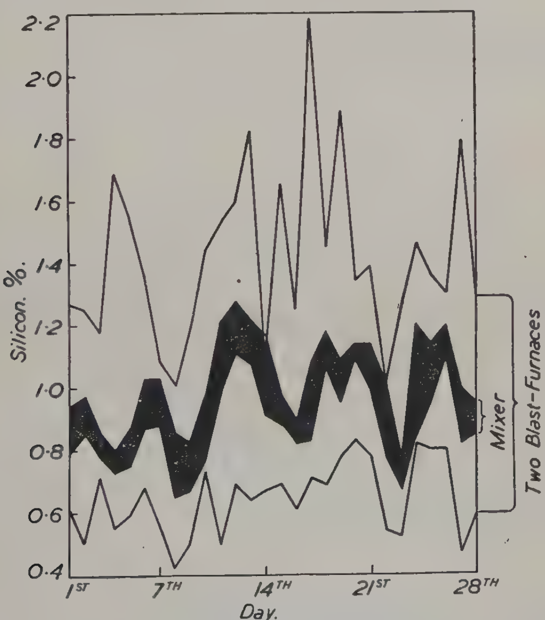


FIG. 7.—Daily Range of Silicon Contents of Blast-Furnace and Mixer Casts.

tapping is adjusted at the finish. The direction of fuel flow is reversed every half hour early in the heat and at 15-min. intervals in the later stages. Except in the case of ingot iron, it is generally plant practice to clear the bath thoroughly before attempting to ore. Over-oreing is avoided, and with the normal limestone burdens carried little flux is necessary to shape up the slags. On special and alloy heats fluorspar, sand and bauxite are used, with lump ore to break up the lime and incite the bath to action.

The rod and pour tests are used to judge tapping temperatures,

and the melters check these with optical-pyrometer readings taken by the metallurgical observer.

The oxygen carried in the downtake gases varies between 1% and 4%, and each furnace is checked by Orsat tests at regular intervals to control combustion.

(e) *Finishing the Heat.*

For testing the steel-bath samples there is a well-equipped laboratory on the outer end of the charging platform between *E* and *F* furnaces. Carbon is determined by colour, combustion and "Carbanalyser" methods by shifts of experienced chemists. Rapid accurate estimations are made of manganese, phosphorus, sulphur and, when required, of nickel, chromium, &c. A slag tester keeps the melter informed of the composition of the slag. Established rules concerning proximity of ore additions to alloying or tapping are obeyed, and on all special heats the last few points of carbon are rodded out.

(f) *Tapping.*

Present tap-hole practice has given good results for several years. The hole is stopped from the front with a mixture of 10% ground coal and 90% crushed burnt magnesite mixed to a stiff pug. From the pit-side the hole is filled with ½-in. burnt dolomite and finally plugged with a ball of plastic clay. When opening the hole, the clay ball is removed, the hot dolomite raked out and the chill opened with the oxygen lance. A pneumatic-tyred hand buggy, fabricated from butt-weld pipe, carrying two bottles of oxygen, is used to run the gas to backstandings for use on the tapping hole. The diameter of the tap-hole is such as to allow the metal to run out at the average rate of 15 tons per min. Tap-holes are remade in the traditional way with 4-in. or 6-in. pipe, depending on the speed of run-out desired for special heats.

Pit Practice.

Steel is tapped at Kembla into conical ladles of 160 tons capacity, 13 ft. 9 in. high, 11 ft. 7 in. in dia. at the top and 10 ft. in dia. at the bottom. All ladles are double-stopper-rigged. Ladle linings are not insulated, but consist of a 3-in. safety lining of firebrick and a 6-in. working lining of special clinker common brick. Daubing of linings is not practised. The average number of heats per ladle lining is twelve. Ladles are heated to 600° F. by coke-oven gas.

Stopper-rod assemblies are made up by one man. The rod, 15 ft. long and 2 in. in dia., takes a firebrick sleeve with a 2⅛-in. bore. Imported graphite stopper-heads are keyed on in the usual way, and the assemblies are thoroughly dried in a vertical oven fired with coke-oven gas.

TABLE VII.—*Mould Data.*

Mould: Used for:	25 in. × 21-in. Standard Wide-End-Down. Rimming and Semi-Killed Steels.	29 in. × 24-in. Wide-End-Down. Large Beams.	38 in. × 20-in. Wide-End-Down. Standard Slab Mould.	25 in. × 21-in. Wide-End-Up. Killed Alloy and Special Steels.	25 in. × 21-in. Wide-End-Down. Spring Steel.
Walls	Corrugated.	Corrugated.	Corrugated wide side.	Corrugated.	Corrugated.
Height	77 in.	80 in.	78 in.	...	77 in.
Overall mould section:					
Top	$34\frac{1}{2}$ in. × $30\frac{1}{2}$ in.	42 in. × $36\frac{1}{4}$ in.	$47\frac{3}{4}$ in. × $31\frac{1}{2}$ in.	...	$36\frac{1}{2}$ in. × $32\frac{1}{2}$ in.
Bottom	$39\frac{3}{4}$ in. × $35\frac{3}{4}$ in.	$45\frac{3}{4}$ in. × 40 in.	$54\frac{1}{2}$ in. × 36 in.	...	$39\frac{3}{4}$ in. × $35\frac{3}{4}$ in.
Contour:					
Top	$23\frac{3}{4}$ in. × $19\frac{3}{4}$ in.	28 in. × $22\frac{1}{4}$ in.	$36\frac{3}{4}$ in. × $18\frac{1}{2}$ in.	...	Square tile head
Bottom	$25\frac{3}{4}$ in. × $21\frac{3}{4}$ in.	$29\frac{3}{8}$ in. × 24 in.	38 in. × 20 in.	...	$25\frac{3}{4}$ in. × $21\frac{3}{4}$ in.
Wall thickness:					
Top	$5\frac{3}{4}$ in.	7 in.	$6\frac{1}{2}$ in.	...	$4\frac{3}{8}$ in.
Bottom	$7\frac{1}{8}$ in.	8 in.	8 in.	...	$7\frac{3}{8}$ in.
Thickness of corners:					
Top	$4\frac{1}{8}$ in.	$5\frac{3}{4}$ in.	$5\frac{1}{4}$ in.	...	$4\frac{1}{2}$ in.
Bottom	$5\frac{7}{8}$ in.	$6\frac{3}{4}$ in.	$7\frac{1}{4}$ in.	...	$5\frac{7}{8}$ in.
Radii of corners:					
Top	$1\frac{1}{2}$ in.	$2\frac{1}{2}$ in.	$2\frac{1}{2}$ in.	...	...
Bottom	$1\frac{7}{8}$ in.	$2\frac{1}{2}$ in.	$2\frac{1}{2}$ in.	...	$1\frac{7}{8}$ in.
Taper per ft.	0·31 in.	0·263 in.	0·19 in.	...	...
Height, base to hot top	...	...	...	...	62 in.
Mould weight	5·05 tons	7·74 tons	8·0 tons	...	5·13 tons
Ingot weight	4·40 tons	5·79 tons	6·53 tons	...	4·37 tons
Weight ratio	1·15 to 1	1·335 to 1	1·225 to 1	...	1·17 to 1
Number of corrugations:					
Wide side	2	5	...	...	...
Short side	2	4	...	...	...
Banded	Not	$13\frac{1}{2}$ in. × $1\frac{1}{2}$ in.	Not	...	Not
Average mould life	97 heats	93 heats	95 heats	...	...

Overflow and flush slag is taken off in 300-cu. ft. cast-iron thimbles and removed from the pit on Pollock-type cars. The pit is provided with the necessary accessories for the rapid cleaning up of scrap and debris.

Moulds.

All the steel is top-poured. Table VII. incorporates the details of mould design. It will be noted that all moulds have corrugated contours; such has been the practice for several years. Contemporary operators differ in their opinions on the relative merits of straight-sided and contoured ingots for blooming-mill feed. On the other hand, multi-sided ingots are universally used for forging. Exact evaluation of the advantages of a contoured milling ingot is difficult, but it is accepted here that with steels of similar quality, poured under precise conditions of temperature and speed, the corrugated ingot has a stronger skin and cracks less in the blooming mill than the straight-sided ingot. Corrugation adds nothing to the cost of the mould, and, provided that the design and mould life are satisfactory, contouring is good insurance.

The Table shows that the mould life at Kembla averages nearly 100 heats, but moulds are by no means used to destruction. Mould rakes are segregated, and as the walls progressively deteriorate from alligator cracking, the groups are used for ingots where the surface condition of the product is of minor importance.

Numerous experiments have been undertaken to determine the most satisfactory iron for mould manufacture. It has been found here that the composition of the iron can vary considerably without adverse effect. Moulds are cast at 1180° C. minimum with a direct-metal mixture of two parts of basic iron with one part of foundry iron, preferably to give between 0·9 and 1·3% of silicon and not more than 2·3% of manganese. When both blast-furnaces are producing high-manganese basic iron, cupola metal is added to obtain the desired composition. The following examples are typical enough of Kembla's ingot-mould-making practice of modifying basic iron by an admixture of a less manganiferous iron:

No. of Heats.	Silicon. %.	Sulphur. %.	Phosphorus. %.	Manganese. %.	Carbon. %.
123	1·2	0·03	0·21	2·1	4·2
121	0·9	0·04	0·10	1·5	4·2
117	1·9	0·03	0·48	1·6	4·0
109	1·4	0·02	0·54	1·6	4·1
107	1·5	0·04	0·26	1·9	4·2
100	2·0	0·02	0·50	1·6	3·9

Tests on this plant have indicated that the rest period has the most pronounced influence on mould life. The period at Kembla is not standard and may vary from 2 to 10 hr. Ingots should be

stripped as soon as they may be and the moulds allowed to cool to 150–200° F. before being used again.

Hot-top practice is varied. Alloy and some other special grades are poured into wide-end-up corrugated moulds seated on a spigotted stool. Superimposed fixed heads are used. Both ends of the mould and the base of the head casting are machined. Dead-killed spring steels are cast into wide-end-down moulds with a recessed tile head. This is a utility mould suitable for certain types of steel.

Mould Preparation.

Perhaps the most difficult part of quality steelmaking is the pouring of consistent high-grade ingots with good surface characteristics. Surface quality is influenced by several factors, of which mould condition is one of the most important. Undoubtedly steel reconditioning costs vary directly with the care given to moulds and stools prior to casting.

Primarily, a high standard of cleanliness is essential. Secondly, mould wash, if used, should be carefully applied. Experience at Kembla has shown that no mould wash at all is far better than an indiscriminate application. The choice of one from the numerous mould coatings available may depend upon the type of steel to be poured and the method of pouring.

There is no standard mould coating at Kembla. Graphite wash and brine solution were tried and rejected. Dry tar sprayed on at the right mould temperature does a good job. The coating should be thin, hard and glossy. The best surfaced ingots here are cast in uncoated moulds. While hot from the previous heat the moulds are washed down with fresh water, which loosens accretions. When dry they are scrubbed down with long-handled wire-brushes. Finally, compressed air is used to clean the mould wall and the stool thoroughly. A few minutes before casting, a length of corrugated kraft paper in the form of a large cylinder is dropped on to the stool. This has given good results in preventing stool splash. Stools are dished and spigotted to form an effective seal, and the small crevice between the mould and stool is filled with grains of ferro-silicon poured down a funnel.

Pouring Practice.

Following the establishment of a satisfactory pouring practice, constant supervision is necessary to maintain a high standard. Consignments of nozzles, stopper-heads, sleeves, &c., should be carefully checked for quality and size. The workmanship in rod assemblies must be inspected, stopper riggings on ladles kept in perfect condition, stopper and nozzle settings examined and pouring crews encouraged to teem cleanly. To achieve a consistent standard entails a lot of persistent work. Nozzle sizes at this plant have varied during the past ten years. Out of the multitude of experi-

ments some axioms governing pouring procedure have been formulated.

All grades of steel are top-poured. For any grade there appears to be an ideal pouring temperature for a given pouring speed. Ingots so poured into scrupulously clean moulds of modern design and then satisfactorily soaked will roll with a minimum of cracking in the blooming mill. Should the heat be poured too hot or too fast, the results will be indifferent. For some time $1\frac{1}{2}$-in. composite magnesite ring nozzles were used for most grades, with pouring speeds of 2·5–2·75 tons per min. Experiments proved that increasing the pouring rate to 4 tons per min. and lowering the pouring temperature enhanced the surface condition of the ingots without impairment of rolling quality. At present the standard shop nozzle is $1\frac{3}{4}$-in. plain fireclay, but the size ranges from $1\frac{1}{2}$ in. to $2\frac{1}{4}$ in. according to the grade of steel that is to be poured. Rimming steel of 0·08–0·10% carbon is poured through $1\frac{3}{4}$-in. nozzles and at a temperature 40–50° F. hotter than semi-killed steel of the same carbon content. This grade is allowed to rim-in until a central molten area of 9 sq. in. remains, when it is capped with rolled steel plate caps weighing 150 lb.

Alloy steel also is teemed with $1\frac{3}{4}$-in. nozzles with careful control of the temperature. Transformer steel, containing 4·5% of silicon, is teemed through $2\frac{1}{4}$-in. nozzles after reladling twice through 3-in. nozzles, for cool steel and clean ingot surfaces.

Pouring temperatures are checked by a disappearing-filament optical pyrometer and comparable figures are obtained from heat to heat. Stools sometimes are coated with tar, but as a rule they receive no preparation. The average stool life is 95 heats from plates 9 in. thick.

For any given teeming temperature, fast pouring rates produce the cleaner-surfaced ingots with a tendency to an indifferent rolling response. Reduced pouring rates produce ingots inferior in surface quality but with improved results in the mill.

Maintenance.

Continuity of production depends largely upon the excellence of the mechanical, electrical and bricklaying maintenance organisations. Frequent inspection of plant is the backbone of good maintenance. Certain items of plant at Kembla are inspected daily. Once weekly all the furnaces, with auxiliary equipment, are carefully examined above and below floor level. An estimate of refractory and mechanical repair requirements is recorded and a copy forwarded to the foreman bricklayer and foreman mechanic, who then cooperate to have repairs effected without delay. This system works well and assists the tonnage rate by eliminating unforeseen delays.

Accumulations in downtakes are removed at regular intervals, and slag-pocket deposits on fixed-fuel furnaces are removed at stipulated times.

Slag Control.

In Australia, as in other countries, the purchaser has become more critical of the material that he buys. Rapid expansion of industry here has contributed to this, and research for cheaper steels with properties comparable with the more expensive alloy steels is stimulated. The manufacture of repetition parts on automatic machines demands uniformity in feed. These considerations have placed on the steelmaker the onus of producing the required quality consistently from heat to heat. Closer tolerances in chemical analyses have to be met, and in some instances orders are endorsed for grain size, cleanliness and other special requirements. Open-hearth operators have had to pay closer attention to quality and establish practices to meet these requirements.

It is realised that our predecessors did endeavour to finish heats with " good slags," but generally the slags were high in lime for all grades of steel, frequently with unfortunate economical and metallurgical results. The technique of basic open-hearth operation has made great strides forward in the past twenty years, the most cogent stimulus having been derived from research work on slags and slag-metal reactions. To such work may be attributed much of the improved qualitative perspective in the furnacing of steel.

Slag control may be defined as the step in the process of steelmaking that is directed to the adjustment of the slag composition to the best advantage. It gives the metal the desired condition at tapping and, associated with suitable deoxidation and temperature control, produces steel of the required composition, type and uniformity in the mould at the lowest cost.

A review of contemporary literature on this subject reveals that there are nearly as many practical systems of control as plants, but it is obvious that any system to be successful must be developed compatibly with local conditions. Consistent high quality is the primary consideration, and if this can be obtained with economies, however small, the interest of everyone concerned is assured. The system should be as simple as possible, reduced to terms easily understood by practical furnacemen and policed by metallurgical observers.

The practice of slag control at Kembla dates from 1932, since when investigation has been continuous. Many theories and methods were tested and rejected before finally the practice was adopted of depending entirely on the analysts for information on the slag and metal in the furnace. There are two chemists on the floor for each shift, one senior man on steel analyses and one junior on slags. Rapid methods are used for lime, silica and iron oxide in slags. Lime results are obtained within 30 min. of spooning the slag from the bath, silica within 35 min., and iron protoxide or total iron in 15 min.

With the available raw materials, the phosphorus pentoxide

carried in the slag with a 9% slag volume averages 1%; hence it is possible to regulate the lime-silica ratio within wide limits without danger of rephosphorising the metal. Therefore, the slag oxidation is able to be kept low and the residual manganese high with valuable

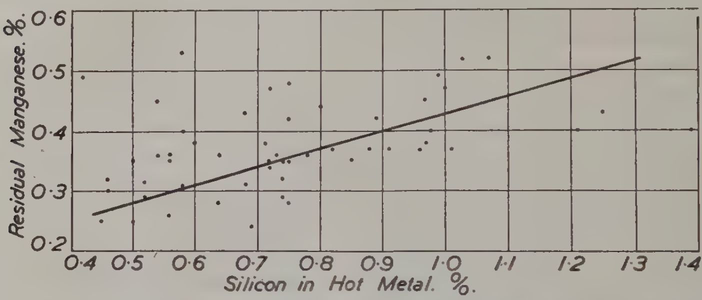


FIG. 8.—Silicon Content of the Hot Metal Plotted against the Residual Manganese.

savings in ferro-manganese consumption. Producing structural grades with 0·4–0·6% of manganese, the plant has made 7,000 tons of steel in consecutive heats without adding ferro-manganese to the bath or ladle. On all grades the plant has worked for a full month using an average of 1·5 lb. of 78% ferro-manganese per ton of ingot,

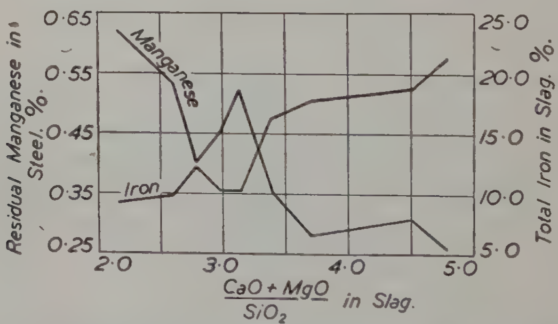


FIG. 9.—Relationship of the Slag Basicity to the Residual Manganese and to the Total Iron in the Slag.

notwithstanding that some of the heats contained 1·7% of manganese.

Figs. 8 and 9 indicate the relationship between slag basicity, residual manganese and total slag oxidation.

The introduction of a 1200-ton hot-metal mixer in 1940 improved operations further. From the analyses of mixer samples the melters are able to charge the furnaces more accurately to melt

within the carbon range specified. Limestone is saved and "bottom" heats are fewer. The smoother, steadier working of the furnaces facilitates the metallurgical control.

(a) *Production of Semi-Killed Steels.*

The analysis range of semi-killed steels is as follows :

Carbon.	Phosphorus.	Manganese.	Silicon.	Sulphur.
0·1–0·35%	0·06% max.	0·4–0·8%	0·3% max.	0·06% max.

These heats are poured into wide-end-down 25 in. × 21-in. corrugated moulds with typical convex ingot tops. Furnace charges for such heats are :

	160-Ton Heats.	230-Ton Heats.
Mill scrap	25 tons	35 tons
Hot metal (Si 0·9%) . . .	115 tons	195 tons
Manganiferous ore . . .	12 tons	46 tons
Limestone	8 tons	11 tons

When the slag is made up, the bath is sampled for metal and slag. Carbon, manganese and phosphorus are estimated in the metal, and lime, silica and iron protoxide in the slag. The melter proceeds to work the heat according to plan. Manganiferous lump ore is fed to reduce the carbon, and sand is added to reduce the basicity, if necessary. The schedule for the sand addition, for instance, for the 160-ton heat, is as follows :

SiO_2 in slag. % .	10	11	12	13	14	15	16	17
Sand required. Lb. . .	2100	1900	1500	1200	900	800	600	300

If the slag is too siliceous, limestone chips are charged.

Kembla experiments confirm the finding of Earnshaw Cook [1] that carbon is necessary for the sand to be effectual in reducing the proportion of iron protoxide; the bath carbon must exceed 0·3% when the sand is added. The diminution in the iron oxide concentration following the addition of sand is out of all proportion to the dilution. It may be assumed that a partial replacement of iron oxide by silica occurs in lime/iron-oxide compounds, allowing some iron oxide to migrate to the metal and effect a slight oxidation of carbon. At the same time there is a reversion of manganese, to an extent governed by its degree of concentration in the slag and metal and the iron oxide content of the slag. The examples given in Table VIII. indicate the practical application of controlled lime-silica ratios for semi-killed steels with up to 0·35% of carbon.

Ferro-silicon additions are made according to the proportion of iron protoxide in the finishing slag.

[1] *Transactions of the American Society for Metals*, 1937, vol. 25, pp. 325–419.

TABLE VIII.—*Application of Controlled Lime-Silica Ratios to Semi-Killed Steels.*

Heat No. :	*E*136.	*B*140.	*D*278.
Charge :			
Mill scrap	40 tons	40 tons	30 tons
Hot metal	110 tons	111 tons	120 tons
Limestone	7 tons	7 tons	6 tons
Analysis of hot metal :			
Silicon	0·9%	0·9%	0·9%
Manganese	2·1%	2·1%	1·9%
Run-off slag	1 pot	1 pot	1 pot
Bath :			

*E*136. — Bath:

Time.	Addition.	C. %.	Mn. %.	FeO. %.
9.10	...	0·58	0·43	9·6
9.25	Sand 0·1 ton	...	...	...
	Ore 0·8 ton	...	...	...
10.10	...	0·27	0·55	...
10.22	...	0·20	0·56	...

*B*140. — Bath:

Time.	Addition.	C. %.	Mn. %.	FeO. %.
12.55	Ore 0·9 ton	0·85	...	14·0
1.42	Sand 0·4 ton	0·43	0·31	...
2.15	...	0·34	0·38	...
2.28	...	0·30	0·38	...
2.37	...	0·24	0·42	10·4
2.43	...	0·22	...	...

*D*278. — Bath:

Time.	Addition.	C. %.	Mn. %.	FeO. %.	SiO_2. %.	CaO. %.
11.15	Ore 1·7 ton	1·00	0·38	14·3	14·4	31·7
11.57	Sand 0·9 ton	0·46	0·42	9·8	...	...
12.08	Ore 0·4 ton	0·45	0·43	7·7	...	...
12.24	...	0·36	0·48	...	...	...
12.32	...	0·30	0·51	6·2	...	...
12.41	...	0·24	0·52	...	...	...
12.50	...	0·22	...	...	...	...

Heat No. :	*E*136.	*B*140.	*D*278.
Ladle additions :			
Ferro-silicon (76%)	0·22 ton	0·23 ton	0·20 ton
Ferro-manganese (78%)	Nil	0·25 ton	Nil
Coke	0·27 ton	0·18 ton	0·14 ton
Ladle analysis :			
Carbon	0·28%	0·30%	0·25%
Phosphorus	0·018%	0·015%	0·029%
Manganese	0·55%	0·54%	0·55%
Silicon	0·08%	0·10%	0·09%
Sulphur	0·028%	0·038%	0·040%
Ingot tops	Convex	Convex	Convex
Aluminium per ton	0·25 oz.	0·15 oz.	Nil

Kembla practice for low- and medium-carbon semi-killed heats is along the following lines :

(*a*) The amount of run-off slag is carefully watched and the take-off is constant from heat to heat for equal charge compositions and metal analyses.

(*b*) Slag volumes are kept as low as is consistent with effective coverage.

(*c*) Finishing slags are run to a lime-silica ratio of 2·0 or 2·2 to 1.

This practice improves the furnace yield by reducing the iron losses in the slag and keeps the residual manganese high, with savings in alloy consumption. For any given concentration of manganese in the charge the residual manganese will vary inversely with the basicity of the finishing slag. The average composition of the finishing slags from fifty semi-killed heats was :

SiO_2.	FeO.	Fe_2O_3.	Al_2O_3.	MnO.	CaO.	MgO.	P_2O_5.
17·7%	7·7%	4·0%	4·3%	23·3%	35·1%	6·8%	1·1%

Critical examination of the figures for three years of production proves that sand intelligently used does no damage to banks and bottoms. Dry sand added to the basic furnace becomes dissolved in the slag within a few minutes. It has no tendency to agglomerate and move to the banks. Sand should be regarded as a necessary basic open-hearth flux, and the controlled use of it recognised as a valuable aid in the production of basic steel.

Several hundred thousand tons of steel have been made at Kembla carrying sufficient residual manganese to be independent of ferro-manganese addition. Such steel is of consistently high quality, its physical tests are excellent, and it rolls well with a minimum of reconditioning.

(b) *Production of Phosphorised Sheet Bar.*

A further interesting example of slag control is the production of sheet-bar ingots to the specification :

Carbon.	Phosphorus.	Manganese.	Silicon.	Sulphur.
0·14% max.	0·06–0·09%	0·45% max.	0·10% max.	0·06% max.

Formerly this steel was made by furnacing for a low-carbon heat and adding ferro-phosphorus to the ladle. The method has been superseded by controlling the reversion of phosphorus to the bath metal from a finishing slag of suitable composition. Some of the limestone burden is replaced by phosphate rock and the slag basicity is adjusted in the finishing stages of the heat. The slag oxidation is kept low and the bath is kept hot. The phosphate rock contains 85% of the tribasic salt. On charging 20 lb. of rock per ton of ingot, the finishing slag will contain about 3% of phosphorus pentoxide, a proportion suitable for easy manipulation and control. Logs of

TABLE IX.—*Logs of Typical Heats for Phosphorised Sheet Bar.*

Heat No.:	*G*138–9.		*G*140–1.	
Charge:				
Scrap	35 tons		35 tons	
Hot metal	205 tons		205 tons	
Ore	48 tons		44 tons	
Limestone	5 tons		5·1 tons	
Phosphate rock	2·3 tons		2·3 tons	
Hot-metal analysis:				
Silicon	1·1%		0·6%	
Manganese	2·4%		2·2%	
Run-off slag	2 pots		1½ pots	
Bath:	(see below)		(see below)	
Ladle addition	No. 1.	No. 2.	No. 1.	No. 2.
Ferro-silicon (76%)	0·17 ton	0·18 ton	0·18 ton	0·18 ton
Ladle analysis:				
Carbon	0·08%	0·08%	0·09%	0·08%
Phosphorus	0·08%	0·08%	0·09%	0·09%
Manganese	0·35%	0·34%	0·37%	0·39%
Silicon	0·05%	0·05%	0·05%	0·05%
Sulphur	0·023%	0·024%	0·025%	0·025%

Bath, *G*138–9:

Time.	Sand.	C. %.	Mn. %.	P. %.	FeO. %.	SiO_2. %.
9.15	0·45 ton	...	...	...	...	...
10.40	...	0·40	...	0·08	8·5	20·2
11.30	...	0·10	0·43	0·07	...	...
11.40	...	...	...	...	8·7	...
11.55	...	...	0·43	...	...	...
12.05			Tap			

Bath, *G*140–1:

Time.	Sand.	C. %.	Mn. %.	P. %.	FeO. %.	SiO_2. %.	CaO. %.
11.15	0·40 ton	0·18	0·42	0·045	...	...	...
11.30	...	...	...	...	9·9	18·4	35·8
12.04	...	0·08	0·47	0·07	...	...	...
12.22	...	...	0·43	...	...	...	...
12.35	...	...	...	...	10·3	...	...
			Tap				

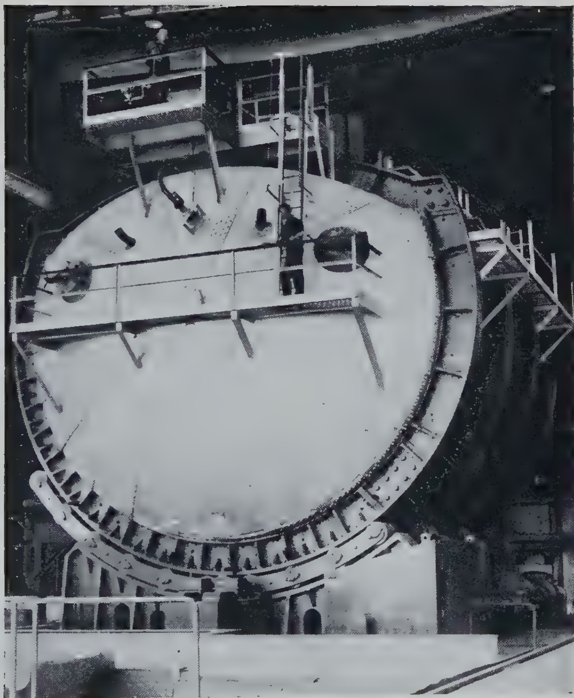


FIG. 10.—1200-Ton Hot-Metal Mixer.

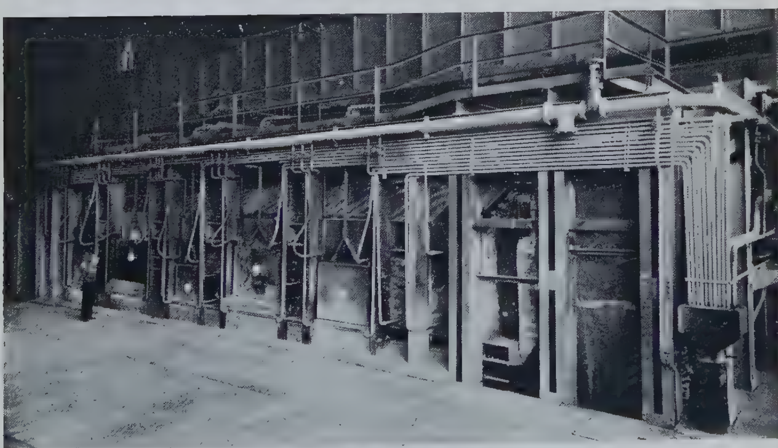


FIG. 11.—Charging Side of *G* Furnace.

[*Knight.*

[*To face p.* 272 P.

FIG. 12.—Burner Arrangement on the Fixed-Fuel Furnaces.

FIG. 13.—Valve Pit of *G* Furnace.

[*Knight.*

[*To face p.* 273 P.

typical heats are shown in Table IX. and slag compositions in Table X.

This practice was introduced as a war-time expediency and has given satisfactory results. Quick and accurate control is essential to success. Furnacemen soon become expert in the adjustment of conditions.

TABLE X.—*Slags of Sheet-Bar Heats.*

Composite Samples.

Number of Heats :	24.	35.	11.	15.
SiO_2. % . . .	17·2	16·6	18·3	18·3
FeO. % . . .	12·0	13·2	12·1	9·5
Fe_2O_3. % . . .	4·4	3·1	3·7	3·7
Al_2O_3. % . . .	5·4	4·1	4·2	3·3
MnO. % . . .	24·3	26·8	27·7	28·3
CaO. % . . .	27·3	26·8	25·0	28·2
MgO. % . . .	6·0	6·0	7·0	5·7
P_2O_5. % . . .	3·4	3·4	2·0	2·8

(c) *Production of Rimming Steel.*

Practically the whole output of the fully open type of steel is rolled into high-finish deep-drawing automobile sheets. Open-hearth operators are aware of the close attention and co-operation required for the production of high-grade ingots for such requirements. Much of the deep-drawing steel that is made abroad is produced from 40% pig-iron charges. In some plants it is considered that deep-drawing grades cannot be made satisfactorily from high hot-metal charges. When this grade of steel came into demand at Kembla in 1937 it was necessary to avoid interference with the existing open-hearth and blast-furnace routine. A practice thus became established with around 70% hot-metal charges, from which rimming ingots of first quality with thick skins and a high degree of cleanliness are obtained.

Typical logs of rimming-steel heats are shown in Table XI.

The charge ore is basic, containing 2% of manganese. The logs show residual manganese somewhat higher than in oversea plants. Here it varies between 0·17% and 0·25%, and it is found that, with other conditions satisfactory, up to 0·25% has no adverse effect on quality. Deoxidation charts made available to melters show the amount of aluminium for the ladle, based on the total iron in the slag and the residual manganese in the metal. The amount varies from 60 lb. with 28% of iron and 0·15% of manganese to 5 lb. with 17% and 0·26%, respectively. It will be observed that the total-iron figure is used as a measure of slag oxidation. From the FeO figure erratic results may occur with high-lime slags on heats tapped below 0·10% of carbon. In such slags there is a wide variation in the

TABLE XI.—*Logs of Typical Heats of Rimming Steel.*

Specification :	Carbon.	Phosphorus.	Manganese.	Silicon.	Sulphur.	Copper.
	0·08–0·10%	0·04% max.	0·32–0·40%	Residual.	0·035% max.	0·10% max.

Heat No. :	C73.	D43.	F249.
Hot metal	120 tons	121 tons	124 tons
Scrap	30 tons	30 tons	27 tons
Limestone	15 tons	15 tons	15 tons
Ore	27 tons	29 tons	24 tons
Total metallic	168 tons	170 tons	167 tons
Previous heat tapped	5.23 P.M.	10.30 A.M.	3.37 P.M.
Commenced to charge	6.50 P.M.	10.50 A.M.	4.42 P.M.
Melted	...	9.00 P.M.	2.15 A.M.
Tapped	8.20 A.M.	12.22 A.M.	3.38 A.M.
Run-off slag	1 full pot.	1 full pot.	1 full pot.
Bath additions :			
Ore	4·0 tons	5·0 tons	1·0 ton
Limestone	Nil	2·5 tons	Nil
Ladle additions :			
Ferro-manganese (78%)	0·4 lb.	0·35 lb.	0·35 lb.
Coke	Nil	0·09 lb.	0·07 lb.
Aluminium	0·013 lb.	0·007 lb.	0·013 lb.
Analyses :			
Hot metal :			
Silicon	0·8%	1·3%	0·7%
Manganese	2·9%	2·4%	2·6%
Bath at melt :			
Carbon	1·0%	1·5%	0·27%
Manganese	0·27%	0·52%	0·26%
Phosphorus	0·025%	0·025%	0·020%
Sulphur	...	0·028%	...
Bath, tapping :			
Carbon	0·07%	0·05%	0·06%
Manganese	0·22%	0·19%	0·21%
Phosphorus	0·01%	0·01%	0·01%
Slag :			
SiO_2	11·2%	13·0%	12·0%
CaO	40·4%	37·6%	36·1%
Total iron	22·5%	19·6%	23·5%
Ladle :			
Carbon	0·08%	0·09%	0·09%
Manganese	0·40%	0·32%	0·34%
Silicon	0·008%	0·009%	0·007%
Sulphur	0·024%	0·029%	0·020%
Phosphorus	0·010%	0·010%	0·008%
Copper	Nil	Nil	Nil
Pouring :			
Nozzle. Imported clay	1¾-in.	1¾-in.	1¾-in.
Stopper	Graphite	Graphite	Graphite
Temperature	Good	Good	Good
Aluminium per mould	3 oz.	4 oz.	2 oz.
Ingot weight	3·4 tons	3·4 tons	3·4 tons
Total weight	156·4 tons	156·4 tons	159·3 tons
Stoppers	Clean	Clean	Both slight leak.
Rimming action	Brisk, falling. Rim 1–2 in.	Active, falling. Rim 2 in.	Even rim. Fairly brisk.
Ingot inspection	Clean. Good surface.	Good surface.	8 ingots slightly splashed.
Ladle skull	Nil	Nil	0·67 ton
Cardboard used	Yes	Yes	Yes

Fe_2O_3 present, and more consistent results have been obtained by using the total-iron results.

When making rimming heats it is desirable to keep them hot right through. The melting-down carbon should be such that the furnace will take from 1 to 3 tons of ore in order to maintain an active bath boil right up to the tapping point. This is essential to the production of ingots free from skin blow-holes. A further requirement when running high-metal heats is to take sufficient and constant quantities of flush slag. If this aspect is neglected much furnace time will be lost in reconditioning the finishing slags. No effort should be made to economise in limestone, which, it will be noted, amounts to 210 lb. per ton of ingots, for such procedure would be more than offset by loss of operating time in waiting for the iron oxide to build up in the slag. Slag volumes average 15%.

Should the slag chemist report a suitable basicity the heat is ored

TABLE XII.—*Typical Rimming-Steel Slags.*

Heat No.:	*B*127.	*D*380.	*A*26.	*A*32.	*B*211.	*B*215.	*E*706.
SiO_2. %	9·3	10·3	9·6	11·5	9·0	12·0	10·7
FeO. %	26·7	14·2	...	...	...	...	...
Fe_2O_3. %	7·7	14·7	...	...	...	...	...
Al_2O_3. %	4·2	3·7	...	...	...	...	...
P_2O_5. %	0·9	0·9	...	...	...	...	...
MnO. %	10·5	11·5	...	...	...	...	...
CaO. %	31·5	33·9	35·2	37·4	34·3	40·2	45·0
MgO. %	9·2	10·8	...	...	...	...	...
Total iron. %	26·2	21·3	26·3	21·1	28·2	23·7	21·3
CaO/SiO_2 ratio	3·4	3·3	3·7	3·2	3·8	3·3	4·2

down in the usual way. Oreing is complete at least one hour before tapping. Should the slag come up more siliceous than is desired, sufficient quantities of dry limestone chips are charged. Burned lime is expensive and difficult to store without acquiring moisture. Partly hydrated lime is considered to be a potential source of hydrogen and a cause of thin-skinned ingots.

All slags are not fully analysed as a matter of routine, for the control system supplies the necessary information from heat to heat. Composite samples of slag are made up periodically comprising those from 15–20 heats. Some typical single slags are shown in Table XII.

Rimming steel is tapped hotter than semi-killed steel of similar carbon range. The melter's practical methods are checked by the metallurgical observer with a disappearing-filament optical pyrometer. The first helper slags a 4-in. dia. spoon and dips deeply for metal, withdrawing the spoon to just inside the door spy-hole. By tilting the spoon the observer is able to get a quick " shot " at the bare metal, and with practice becomes adept.

The objective is to pour ingots that rim actively in the moulds

with 1–2 in. of fall. Such ingots show 4 in. of rim depth on a 25 in. × 21 in. × 63-in. ingot. This gives the sheet-maker ample latitude in the subsequent processing. Aluminium in the pit is regarded as a corrective for slightly over-oxidised steel, but the condition of the metal from the furnace must be satisfactory.

(d) *Production of Alloy and Forging Steels.*

Special steels in alloy and plain-carbon grades are made in the 160-ton furnaces. Written instructions are issued and obeyed. The same principles of slag control apply, and the lime/silica ratios vary between 2·5 and 2·7. Heats are slightly overcharged with lime, and small, regular additions of sand are made in the early stages to correct the slag composition and inhibit the rise of FeO. Heats are made with the lowest FeO content in the slag that is compatible with low phosphorus in the metal, and FeO can usually be controlled to a "three-point spread." Special attention is paid to the rate of carbon diminution, and over-oreing is not permitted. Ore is seldom added within two hours before blocking and alloying, the last few points of carbon being shaken out with rabbles. In making expensive alloy grades, flush-slag practice is omitted in order to avoid possible variations and to recover alloy from the scrap. The grain size is controlled entirely in the ladle. All alloys except silicon are added to the bath. These heats are held in the moulds for two hours before stripping and transferring to the soaking pits.

The author is indebted to the General Manager of Australian Iron and Steel, Ltd., for permission to publish this paper, and to the Chief Metallurgist, Mr. H. V. Nicholls, Mr. A. McCahon and other officers for advice in its preparation.

DISCUSSION.

Mr. A. Robinson (Chairman of the Open-Hearth Committee of the Iron and Steel Industrial Research Council; Appleby-Frodingham Steel Co., Ltd., Scunthorpe, Lincs.) presented the paper in the author's absence; in doing so he made the following comments: The raw materials of very high quality, the unlikelihood of any large supply of cheap scrap, and the type and quantities of steel required have decided the process and type of furnace.

The general layout is adequate and normal and one quite usual in Great Britain, with a variation that the ingots are stripped and transferred to the next bay by wall-type stripping and transfer cranes.

It is noted that the mixer is not lined with magnesite, but with high-alumina bricks with a softening point of 1680° C. and no contraction when heated for 2 hr. at 1400° C. It would be interesting to know the thickness of the lining and its life.

The fuels used are of high calorific power, and coke-oven gas and tar can be used on the producer-gas furnaces to revitalise them near the end of the run. In the case of coke-oven gas and tar approximately half the heat is given by each fuel.

The use of a high proportion of molten iron in the charge of practically hematite quality with reasonably low silicon and high manganese contents (phosphorus and sulphur being negligible), and the high quality of the limestone and ore have allowed the designing of very large deep-bathed furnaces, such as are only comparable in Great Britain to the modern tilting furnaces—the depth varying from 35 in. to 44 in.—which are quite in order, considering the small amounts of scrap charged and the considerable agitation of the bath by the strong and early boil which will quickly lift the solid materials from the furnace hearth, although it is stated that bottoms tend to grow and periodical washouts are essential.

The treatment of the flues, uptakes, &c., has been generous and good facilities for examining and cleaning the checkers and accessible flues and valves have been provided.

The dimensions of the furnaces bear a very close resemblance to those of the modern British tilting furnaces, but in some cases the depth is even greater. The slag pockets are very long and comparatively narrow. This will probably protect the checkers to a large extent from entrained slag and dust in the waste gases.

The roof of silica brick, 16–24 in., and the bottom of magnesite brick and sintered magnesite, 32½ in., are of considerable thickness compared with British practice.

The question of insulation, as in Great Britain, is an open one—its principal advantage probably being that of making the walls air-tight. The insulation of the 32½-in. bottom seems hardly necessary, though it may have some small effect in keeping the bottom hot in these particularly deep furnaces.

It is noted that five out of seven furnaces are "all-basic-lined," presumably above slag-pocket level—and the author has evidently a very good opinion of the basic roof, and expects very great advantages from the use of a "proven high-strength thermally satisfactory (and presumably non-spalling and non-peeling) basic brick." Since, as shown in the paper, the roofs are yet of silica brick, the basic roof must still be in the experimental stage. His experience of basic ends and their effect on the slag-pocket slag can be borne out by many users in Britain.

The particulars given of the performance and outputs of two furnaces are good, but can be matched in normal times by British tilting furnaces using phosphoric iron.

The raw materials used in this plant are a melting shop manager's dream: Iron containing 2–3% of manganese, 0·1% max. of phosphorus and 0·04% max. of sulphur, sized limestone and manganiferous ore. With the ores available one would expect a more regular silicon content in the iron.

The problem of basic open-hearth steelmaking under such conditions is obviously somewhat different from that in Great Britain, the metallurgical load being less for similar proportions of iron and the elimination of phosphorus and sulphur not causing any anxiety.

There is no doubt that the charge as shown will come to the boil very rapidly.

The author's methods of slag control are interesting and the presence in the slag of only 1% of P_2O_5 makes possible the use of sand as a flux when required, and allows him to run a very low lime and iron in the slag—offset somewhat by MnO—and a high residual manganese in the metal without danger of rephosphorisation.

The ingot moulds are of a somewhat unusual composition, are comparatively thick-walled and give a reasonable but not particularly good life reckoned in pounds of ingot mould per ton of ingots.

In conclusion I must congratulate the author on his paper, and on being employed in such a paradise of steelmaking.

Dr. E. GREGORY (Park Gate Iron and Steel Co., Ltd., Rotherham): This is an excellent paper, and full of most interesting details. There are, however, certain comments which I should like to make upon it. In the first place, it can hardly be described as representing the "truly" basic open-hearth practice of Great Britain. As Mr. Robinson has pointed out, the composition of the hot metal is what the open-hearth manager here dreams about but never gets. The desired basic iron composition is given as follows:

Silicon.	Sulphur.	Phosphorus.	Manganese.
0·8—1·0%.	0·04% max.	0·1% max.	2·3—3·0%.

At Mr. Knight's plant he has, therefore, excellent raw material to start with, and it is evidently that which has permitted them to

adopt the particular technique described in the paper, since there is obviously not much cause for worry in regard to sulphur and phosphorus.

One of the novelties is the use of sand, referred to on pp. 269 P and 271 P. They apparently use sand for lowering the iron-oxide content of the slag. Personally, I am not satisfied with the explanation given that "the diminution in the iron-oxide concentration following the addition of sand is out of all proportion to the dilution. It may be assumed that a partial replacement of iron oxide by silica occurs in lime/iron-oxide compounds, allowing some iron oxide to migrate to the metal and effect a slight oxidation of carbon." I do not think that that explanation is sufficient. The manganese oxide in the slag, which is very high indeed, must play an important part.

Again, the author says that "sand should be regarded as a necessary basic open-hearth flux, and the controlled use of it recognised as a valuable aid in the production of basic steel." We should hesitate very much to add sand to our own basic open-hearth slags, not from the standpoint of the iron-oxide concentration, but from the point of view of rephosphorisation.

The composition of the ingot moulds is unusual, but, in view of the life which is claimed, I do not see that one can raise any real objection.

When dealing with slag control, the author says that "lime results are obtained within 30 min. of spooning the slag from the bath, silica within 35 min., and iron protoxide or total iron in 15 min." As the Chairman of the Standard Methods of Analysis Sub-Committee, I should be glad if we could have details of the method for determining silica within 35 min. On p. 262 P, the author states that "rapid accurate estimations are made of manganese, phosphorus, sulphur and, when required, of nickel, chromium, &c.," and I should also like to have details of the methods used for the rapid, accurate determinations of sulphur and phosphorus.

There are many other small points in this interesting paper which could be raised. For instance, on p. 265 P it is said that "dead-killed spring steels are cast into wide-end-down moulds." One would have expected dead-killed steel of that quality to have been susceptible to exaggerated primary piping when cast in that manner.

Mr. C. A. Reed (Skinningrove Iron Co., Ltd.): I wish to congratulate the author on the very able manner in which he has dealt with the whole aspect of the basic open-hearth practice in an Australian plant. It is very comforting, in these days in particular, to know that such good results are being obtained.

Several points arise out of the paper which to me appear to be of particular interest, the first of which is the depth of bath. On a fixed furnace does such a depth as 44 in. present any difficulty to the operator in flowing out, when a hole is formed in the furnace bottom,

especially at the base of the front bank? A tilting furnace, working with a similar bath depth, can, of course, be more easily manipulated for such a purpose.

It is interesting to note the extensive use made of basic refractories in these furnaces, and the author's remarks concerning the future possibilities of an all-basic furnace are indeed encouraging. I look forward to the time when we, too, will be able to do more with this type of refractory.

With regard to the ribbed type of roof construction, is any difficulty experienced from dust collecting in the grooves? I have had some experience with ribbed roofs, and one difficulty which faced me was the heating-up of the brick caused by the dust deposits in the grooves, which I found were not always easy to remove.

With reference to the instrumentation of these furnaces, I should be pleased to know more about the furnace draught control. What is the method of operation, and how does it work? Is it worked from the furnace pressure? If so, is the sensitivity such that it responds effectively to furnace reactions?

Finally, I note that sea water is used for all cooling on these furnaces; does any difficulty occur with salt deposits in the pipes or is any undue erosion of the valves or pipe joints caused?

Mr. Richard Mather (Member of Council; Messrs. Pease & Partners, Ltd., Darlington): We are fortunate in having a description of such a very interesting steel plant, which is obviously one of the biggest melting shops in the British Empire. It reflects great credit on the enterprise of the firm which has had the courage to build a shop of these very large fixed furnaces. The Broken Hill Company is associated with the Australian Iron and Steel Company, and between them they have two very large and successful steelmaking shops.

My interest is not so much in the details of furnace construction and operation, with which others here are more competent to deal than I am, but I notice that the author says that this open-hearth shop of seven furnaces has a capacity of 750,000 tons of steel ingots a year. I should prefer to be told how much it can actually produce. I am a little uncertain what "annual capacity" means; we frequently see statements of that kind and find from time to time that they are not strictly comparable. I have added up the individual capacities as shown in Table I. and divided them into 750,000, and I find that it will need 543 charges per furnace per year. That seems to me to be a tight fit, when allowance is made for the necessary time that each furnace will have to be down for rebuilding, and also when one finds, on p. 257 P of the paper, that *F* furnace, which has a nominal capacity of 230 tons (which is the divisor that I have taken into account), was working in the specific period of ten months referred to only on 203 tons per heat. I should be interested, therefore, to know how much this shop has

actually turned out in twelve months' continuous work, which is the criterion that I myself would always prefer to apply to any question of the capacity of a producing unit. However, I have no doubt at all that if we were able to get that figure it would prove to be a high one, a figure which possibly we could not equal in Great Britain in a single shop.

One knows that in dealing with big tonnages of production in a single unit the question of handling the material both into the producing unit and away from it is extremely important, and I notice from Fig. 1 and from the very brief reference at the top of p. 237 P that they are using a method of moving the ingots away from the casting pit to the soaking pits which is new, at any rate to me. I should like to have a little more information on how that arrangement works. I think that that general aspect of plant construction is one which in several papers presented to the Institute from time to time, of a nature allied to the one now before us, has not been given sufficient attention. We all find in our own experience that if we have a small number of furnaces in a shop and one furnace is down, the other furnaces do better, because we can concentrate our mechanical handling appliances and general auxiliary facilities more effectively. I think that this question of mechanical facilities and auxiliaries for handling materials is one which we should constantly keep before ourselves, and, when we have such an opportunity as this, we should try to obtain detailed information on the subject for our own guidance in attempting, if we can, to increase the productive capacity of existing units.

Dr. Gregory has referred to the question of the ingot-mould composition, and has drawn the deduction, I think rightly, that an analysis such as is given here shows that some of the features of ingot-mould composition on which people are occasionally inclined to insist are not necessarily essential. I can say from my own experience in India that there we made ingot moulds of rather more abnormal composition than these so far as phosphorus was concerned —we had not the high manganese—and yet we were able to get lives for ingot moulds very similar to these. There is no doubt that a considerable latitude is possible in regulating the composition of ingot moulds.

Mr. Robinson said that this iron is a steelmaker's dream, and indeed it would be an immense improvement for some of us if we could get anything half as good; but I happen to know that our friends in Australia are not satisfied with it. They were at that time rather exercised in mind that they were a little behind the maximum economy in production of at any rate the ordinary qualities of steel, because their iron contained so much manganese that they could not use the duplex process (which is fairly widely used in America and largely used in India), because the high manganese stood in their way.

Dr. T. Swinden (Member of Council; The United Steel Companies, Ltd., Stocksbridge, near Sheffield): A good deal has been said about the pig iron being ideal, but I think we should also concede that the paper gives evidence of excellent shop control and management. It would be quite impossible to prepare a paper of this kind in such detail unless there was very excellent control, and unless there were facilities for that control. The author is to be congratulated on being engaged in such an excellent plant as well as with such excellent material.

There are points on almost every page of the paper on which one could comment, but mainly this is a record of what is being done with a certain class of material, and it is for us to see whether we can learn anything from it to improve our own practice. On the question of slag control, I entirely agree with Dr. Gregory that the adding of sand is something unheard of here, and one does wonder whether sufficient attention has been paid to the amount of slag produced—after all, 15% is quite considerable—and whether what is required could not be obtained by other means. One has the impression of such excellent control from reading the paper that one hesitates to criticise, but I agree with Dr. Gregory that the statement that "sand should be regarded as a necessary basic open-hearth flux, and the controlled use of it recognised as a valuable aid in the production of basic steel" cannot be accepted for British practice.

On the question of ingot moulds, I have not had the opportunity of examining this very carefully, but I would point out that the wall thickness is high, and I should not regard the lives as being anything phenomenal. I am inclined to agree, having spent a good many years studying this question, that the composition is perhaps not as important as one had thought. However, we have examined our data by statistical methods and we try to control according to the evidence which these methods show us.

One point on which I should like a little information is on p. 237 P, where it is stated that "ingots are cast into moulds on fixed stools in single line"—and remember we are talking of casts of 160 tons capacity. On p. 262 P, however, the author says that "all ladles are *double-stopper-rigged*," which would imply that the not uncommon method of casting two rows alongside is employed. I should be interested to know how these two statements are reconciled.

Finally, I am particularly interested in the section on refractories, and in the basic steelmakers' dream of the all-basic furnace. We have had one or two shots at that, but have not been too successful.

Dr. David Binnie (The Lancashire Steel Corporation, Ltd., Irlam, near Manchester): On p. 257 P the author gives very low figures for the heat consumption per ton of ingots; I should like him to give more details of how these figures were arrived at. Does he include week-end stoppages and all contingencies? We all know

that the quality of the raw materials is very good, and tends to result in a low figure, but I cannot see how he can get such a low figure as 2,862,000 B.Th.U. per ton; in Britain it is more like 4,000,000–6,000,000 B.Th.U. per ton, which includes week-ends and allows for any breakdown or stoppages. It would be of interest, therefore, if the author would say exactly how that figure was arrived at, and also what type of steel was made at the time, which is another important factor.

I notice that all the steel is top-poured. Could the author say whether ascension teeming has been tried by him and has been found unsuitable for his qualities, and, if so, could he state the reason for such a decision?

Mr. T. JOLLY (Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd., Port Talbot, Glam.): Both Dr. Gregory and Dr. Swinden have mentioned the interesting question of adding sand to an open-hearth bath. On reading this paper I formed the opinion that both the author and his Company are to be congratulated on an open-minded approach to their open-hearth problems, and here I would refer to Fig. 7, which gives the silicon contents of the iron. The variations rather surprised me; we have maxima at 2·2% and minima down to 0·4%, while in the mixer we have 1·2% to 0·6%. With their raw materials, that strikes me as rather irregular, and I wonder whether that is not the reason for the addition of sand to the open-hearth bath. I presume that they have a very tight slag control and want more silica on occasions in the slag, and this is one method of getting it conveniently.

Mr. J. N. KILBY (Hon. Member of Council; Messrs. Richard Thomas & Co., Ltd., Scunthorpe, Lincs.): The Australian Company is to be congratulated upon their policy in building the steelworks where they are and in developing raw materials. It should be remembered, however, that in Britain there have been big outputs and many features contributory to these rather similar to those in the plant described in Australia.

Purely as a matter of interest I propose, in a written contribution, to refer to furnaces which have operated in England with Lincolnshire metal, up to 80% of phosphoric iron, and, at the same time, offer criticism of the paper.

To my mind, the load of a basic open-hearth furnace is governed by the phosphorus and silicon in the charge, that is, the slag volume is the biggest indicator of the load.

At Redbourn, we operate fixed-furnace practice with 20–30% of slag. It will be appreciated, therefore, that the Australian process is a totally different proposition and does not impose a load on the furnace structure or capacity such as we experience in Britain, because their slag is under 10%.

Furthermore, they are running 80% of metal with about 4 cwt.

of oxide of iron per ton of steel produced. The resulting reaction is a tremendous heat producer. With their very small volume of slag the wear on their furnace structure must be correspondingly low, for the bigger the slag volume on any open-hearth furnace the greater is the wear on refractories, particularly the roof, linings and ends. The height of reaction in the furnace is more steadily maintained, and this keeps the region above the bath level much more voluminous than in English practice, all in favour of furnace life.

Personally I do not think that 2,000 tons of steel a week, with the materials which they are using, is anything extraordinary. Just before the war we had reached an output of 1,800 tons of steel a week, working on a ratio of 75% phosphoric pig iron, from open-hearth furnaces which were originally of 60 tons capacity but which had since been altered to a nominal 100 tons capacity. I know that comparisons are odious, but I felt that it would be of interest to mention those points, and I think it will be interesting to give particulars of campaigns on furnaces which operated with fully basic materials above the slag arches, including the roof, before the war and just after war broke out, and where the average output was over 1,500 tons per furnace.

Mr. R. H. Myers (The British Iron and Steel Federation, London): With reference to ingot moulds, it will be seen from the analyses of mould irons given on p. 264 P that a relationship exists between the silicon content and the life; as the silicon increases from about 1% to 2% the mould life decreases. This is in line with results given in the Eighth Heterogeneity Report by the Ingot Moulds Sub-Committee.[1] The manganese content is high, but it is probably dictated by the irons available and is not necessarily intended.

Phosphorus appears to exceed the danger limit. J. G. Pearce stated in the Seventh Heterogeneity Report [2] that more than about 0·3% of phosphorus was apt to harden the iron by forming a continuous network of the phosphide eutectic, and results in British practice since reported show a falling off in mould life once the 0·3% mark is exceeded; below this value, however, mould life appears to improve with an increase in phosphorus.

The metallurgical load can be measured roughly by the slag volume carried. The Kembla yield is given as 9%, whereas in British pre-war hot-metal practice this ranged from 14 to 27%, with an average of about 18%. The British war-time slag yield has been increased probably in some cases by some 30–50%.

The insulation of furnace hearths always raises in my mind questions as to whether (i) bottom repairs would be increased owing to the decrease in temperature gradient, and (ii) the insulating properties of the material would suffer after a time owing to com-

[1] *The Iron and Steel Institute*, 1939, *Special Report No.* 25.
[2] *The Iron and Steel Institute*, 1937, *Special Report No.* 16.

pression by the weight above. Diatomaceous earth, however, used in the Kembla furnace, might be so constituted as to withstand high compression and so be able to retain its voids even under the drastic conditions imposed. Information on these points would be helpful.

It is stated on p. 254 P that *G* furnace regenerators and fantails are insulated. Having regard to the large slag pockets, it might have been beneficial to extend the insulation to these also. Much heat must be lost through the relatively thin wickets, the insulation of which would not be difficult; moreover, this material could be recovered for re-use.

Concerning "suspended" roofs, referred to on p. 243 P, these are known in Great Britain as "sprung" roofs. This might be misleading, as over here the term "suspended roof" implies an entirely different construction.

Turning to fuel, the plant is fortunate in being able to switch over from producer gas to coke-oven gas and tar, once the furnace draughting conditions fall off. The resulting improvement in performance is not surprising, seeing that the waste-gas volume for coke-oven gas and/or tar is roughly 30% less, for a given heat input, than that for producer gas alone.

The PRESIDENT (Mr. James Henderson): I should like to say a word about the development in Australia of the steelmaking industry. There is no doubt that the greatest credit is due to the Broken Hill Proprietary Company, who are the owners of the Australian Iron and Steel Company, for the development out there. They started a number of years ago under very great difficulties. It will be noticed from the paper that they have a sea-haul of 1,000 miles for their iron ore, from South Australia to Newcastle and Port Kembla, and in various ways they have shown a spirit of enterprise and energy that is very creditable to them, and incidentally to the British Commonwealth, of which they are proud to be a partner.

One thing not mentioned in the paper is the orderliness and tidiness of the plant of the Broken Hill Company. I had the privilege, perhaps not shared by many in this room, of seeing those plants a little over four years ago, and I only wish that they were some thousands of miles nearer, so that we could all have the benefit of visiting them and appreciating the wonderful work which they have done in making their plants tidy and orderly, with a definite increase in efficiency. It was really an education to me to visit those plants and to see what had been done.

We have marked our appreciation of this paper by awarding the author a Williams Prize, and I am sure you would wish to convey to him, through the Secretary, our admiration for the paper. We have also to thank Mr. Robinson for his presentation of it.

CORRESPONDENCE.

Dr. J. H. Chesters (Central Research Department, The United Steel Companies, Stocksbridge, near Sheffield) wrote: Refractories technologists will be delighted with the very thorough and illuminating way in which the author has dealt with this aspect of the Port Kembla plant.

The author has raised many points on which we should like to comment, *e.g.*, the high lime content of the silica bricks, the low magnesia content of one chrome ore in Table III., and the small cross-section of some of the chrome-magnesite metal-case bricks, but we shall restrict our remarks to the section dealing with bottom maintenance.

The author's statement that "the quality, quantity and yield of steel made in any open-hearth shop is largely dependent on bank and bottom maintenance" will be an added stimulus to those in Britain who are devoting so much time to the study of open-hearth and arc-furnace bottoms. It is true that Australian bottom technique is more like the American than the British, but the information given and the additional data which we hope the author will consent to give should be of considerable value to this country.

Virtually all basic bottoms in England are made and maintained with burnt dolomite ("Basic"). The use of hydrated magnesia in pug form for repairing bottom holes and of raw dolomite for general fettling is therefore of particular interest. So, also, is the suggestion that the "best fettling refractory would appear to be a self-bonding weatherproof ferruginous dolomitic material in uniformly sized acicular particles of high softening point." We presume that the author refers to the type of material produced in America in a rotary kiln, using an addition of iron oxide equivalent to about 5% in the final product. We believe that these particles are rounded, as are also those in our dense-packing mixtures, and hence we should like to know why the author considers an "acicular" character desirable.

The main points on which we should like further information are as follows:

(1) What is the grading of the raw dolomite? Just how "small" is it, and is it free from dust? Does the author use this material because it is cheap and one can "get away with it" or because it has certain advantages over burnt dolomite?

(2) What are the average fettling times on these furnaces and what amounts of raw dolomite, burnt dolomite and calcined magnesite are used per ton of steel made? Does the consumption of fettling material increase with the age of the bottom?

(3) Does the use of bauxite instead of fluorspar in slag-making result in an increased consumption of fettling material?

(4) Is the slag-line cut worse and the consumption of fettling material greater when melting steels with slags having high iron-oxide contents, such as *B*127 in Table XII.?

Mr. H. C. Wood (The Wellman Smith Owen Engineering Corporation, Ltd., London) wrote: From a constructional point of view the open-hearth plant of Australian Iron and Steel, Ltd., at Port Kembla, so ably described in Mr. Knight's paper, is of considerable interest. The choice of stationary furnaces of such large capacity, producing big tonnages of steel, makes it essential that both the furnace charging and casting shops should be of ample width and well provided with charging and crane equipment. It is noticeable, however, that in the text on pp. 236 P and 237 P the spans of the furnace and casting bays are given as being 80 ft. and 67 ft., respectively, whereas the cross-section drawing Fig. 1 indicates that the spans measured from centre to centre line of the columns for both shops are 71 ft. $10\frac{7}{8}$ in. Possibly the 80-ft. dimension for the charging bay includes the platform which extends into the casting bay.

It would have been a welcome addition to the information supplied in the paper if a plan view of the plant had been added. This would no doubt have indicated the position of the 1,200-ton metal mixer relative to the furnaces. It is not clear from the text whether the mixer is located at one end of the plant or at some other point. If the former applies it would seem that the hot-metal crane has to travel considerable distances to serve the various furnaces to be charged. If, therefore, this 100-ton crane runs, as appears to be the case, on the same track as the overhead chargers, the work of the latter must be somewhat hindered. It is, however, recognised that the percentage of scrap and cold pig iron charged is unusually low.

The method of employing a stripper crane of the semi-portal type indicated in Fig. 1, which also serves to pick up the stripped ingots and cross-traverse them to the transfer car located in the adjacent bay, appears to introduce a novel design. It would seem, however, that such a combined stripping and ingot transfer machine, with its two trollies and telescopic side-traversing framework, must be somewhat cumbersome, and that the two units employed, if also used for mould setting, must be kept heavily occupied in handling the large tonnage of steel produced.

Mr. J. Sinclair Kerr (Member of Council; Lancashire Steel Corporation, Ltd., Irlam, near Manchester) wrote: On reading this paper of comprehensive interest, for which we are all indebted to the author and his Company, I was impressed with the difference between the conditions under which we have to work, especially at the present time, and those at Port Kembla. I have examined these diversities of practice, but, of course, much depends on the quality of the raw materials available. Port Kembla is fortunate in the high quality of the charge ores, which have only 3% of silica and 3% of alumina, and the scrap is apparently all, or nearly all, high-grade mill scrap I note with interest that they work to a high hot-metal/scrap ratio, and a heavy ore charge, which results in pronounced bath boils, a practice which they also use for deep-drawing automobile sheets.

They do not seem to be troubled with small oxidisable scrap such as turnings and borings, and the problems of miscellaneous scrap do not arise, *e.g.*, the efforts required to keep down extraneous metals such as copper, &c., and the harmful effect on refractories due to zinc from brass contaminations. I have found zinc impregnated in the checker bricks.

I notice that all their steels are top-poured. We, in Britain, find that when a good surface finish is of great importance ascension teeming is beneficial, even when taking into account teeming speeds, &c. I would have thought that Port Kembla would have had to resort to ascension teeming on occasions, especially since their anti-splash device would be of only limited usefulness in preventing the steel from splashing when the stream of metal hits the stool.

Turning to the subject of mould metal, I notice that they use mould metal with up to 0·54% of phosphorus and obtain a good mould life. The analysis of the mould metal on p. 264 P, coupled with the number of lives, will, no doubt, be studied in detail by the Ingot Moulds Sub-Committee. I notice that the sulphur figures are very low and wonder if this can permit more latitude in other directions. I agree with the author's views on the precautions necessary to ensure a long mould life.

The Kembla management are keenly interested in instrumentation and their furnaces are equipped with well-designed instrument panels. I have recognised the value of endeavouring to equip open-hearth furnaces as fully as possible, but would have liked the author to say what system of instrument maintenance and compilation of records they have developed.

I particularly note the high percentage of tar which is used for firing the open-hearth furnaces. The heat input derived from the tar is 51·8% and that from coke-oven gas 48·2%. It is also stated that, should increased heat input be required, the tar supply would be stepped up, and, further, that high proportions of coke-oven gas are not encouraged, because experience has shown that, when fired at a rate exceeding 50,000 cu. ft. per hr., it tends to "fly" badly to the roof, causing overheating, which is what one would expect. I have noticed it in furnaces on the Continent, and steps were taken to cure this.

Importance is attached to the use of the disappearing-filament optical pyrometer in taking pouring temperatures. I would not have thought that too much reliance could be placed on these readings of liquid steel. Extensive studies may have been made of this method, but I am inclined to think that the author has placed too much reliance on this apparatus for obtaining the pouring temperature of steel.

The supervision of the manufacture of producer gas is, in my opinion, of first importance, no matter how good the coal is.

The description of the development of the design of the regenerators is of very great interest, and I am sure that it would be

much appreciated by those interested in the development of furnace design if this description could be supplemented in the near future with complete thermal analyses of their performances.

The quality of the pig iron and materials will contribute very considerably to the life of the furnaces.

This paper will be widely read in Great Britain, and I should say that the majority of people will look upon the Kembla Works as the steelmaker's paradise.

Mr. G. A. V. Russell (Messrs. Steel, Peech and Tozer, Sheffield) wrote: To those, like myself, who are struggling under war conditions to maintain and improve open-hearth performances in Britain, some of the advantages possessed by Port Kembla, such as its hot metal and liquid-fuel resources, will be a source of envy. This does not, however, detract from one's admiration for the achievements recorded, as the difficulties that have had to be surmounted can be fully appreciated.

The layout of the open-hearth shop is an interesting blend of European and American ideas. The employment of overhead revolving chargers handling pans directly filled on the stage gantry recalls European practice, whilst the general arrangement of the building is more American. If Mr. Knight had to work considerably higher scrap charges, would he still prefer this charging arrangement, or would he favour the American system of loading scrap in pans on drags of cars, which are spotted in front of the furnaces, and thence charged by means of husky non-revolving floor-type machines? I wonder, also, if the overhead chargers are not a slight drawback in restricting the freedom of movement of the hot-metal crane.

The teeming arrangements are rather unusual, bearing in mind the large output. It is not quite clear to me where the requisite moulds are stocked, but I presume that these are stored in various parts of the casting bay out of direct reach of the strippers and are brought within the latter's reach by the general-purpose pit-side crane. In the absence of a layout plan, I would ask how many ingots the ingot transfer car carries at a time, and what is about the average distance that this vehicle must run in delivering ingots to the soaking-pit charging cranes.

In the case of the producer-gas-fired furnaces, it is presumed that burning-out takes place as usual at week-ends, but no indication of the length of the week-end shut-downs is given. Referring to the tar and coke-oven-gas fired units, are these worked continuously without break at the week-ends?

The furnace designs developed at Port Kembla, both in general dimensions and in detail, appear to be as good as anything in the world. It is interesting to observe the progressive increase in roof height that has taken place as successive furnaces have been built or rebuilt to provide greater cross-sectional areas at the centre of the melting chamber. It appears, too, that the throat areas have been

progressively increased, with advantage in both performance and life. The generous size of uptakes provided in the most recent and rebuilt furnaces is a noteworthy and most valuable feature, as are the slag-pocket dimensions that have been adopted. It would be interesting if Mr. Knight would give his experience with the wide jack arches employed in his checker chambers and slag pockets, as they are a decided contrast to the semi-arch usually employed in Britain. If there is one feature about the design of the 240-ton furnace that appears slightly weak, it is the bridge wall. It may be wondered if this should not be strengthened and ventilated, even at the expense of some reduction in slag-pocket volume. The abolition of the usual American fantail flue connection between the slag pockets and the checker chamber and the incorporation of the space that these require in the slag-pocket volume is an excellent feature.

Regarding the furnace performance figures given for *F* and *G* furnaces, it would be valuable if Mr. Knight could give corresponding typical data for one of his 160-ton producer-gas-fired units. It is presumed that these have rather smaller hearth areas than the tar and coke-oven-gas fired furnaces, owing to the greater space required for the port ends with producer-gas firing.

In connection with the employment of two ladles and a bifurcated launder for the large furnaces, are any special means used to ensure an equal flow of steel into the two ladles, so that finishings may be added accurately enough to enable steels of fairly close specifications to be made? The practice of filling-up a steel furnace as much as possible is, generally speaking, an easier way of securing the maximum production than working a smaller size of charge and having to tap more frequently. Usually, however, the quality of steel produced is not so regular as when the whole charge is tapped into a single ladle.

A notable feature of Port Kembla practice is the small slag bulk obtained in spite of the high percentage of hot metal used, which, of course, is due to its low phosphorus and moderate silicon contents. In spite of this, however, I infer that run-off slags are regularly tapped, and estimate that the thickness of the slag covering after running-off is only an inch or two. This condition should be a great help in securing a high rate of output in conjunction with easier conditions on the roof refractories, as the transfer of heat to the metal will be appreciably accelerated when compared with the more usual slag thickness of 4–6 in. It would be interesting to know what saving in time the author considers the employment of a run-off slag to effect under his conditions.

Dr. A. H. Leckie (The British Iron and Steel Federation, London) wrote: There are two points which call for special comment in connection with the design of the author's furnaces:

(1) The unusually large uptakes are to be commended as a

particular point of design to be imitated where possible. It will be observed from Table IV. that the tendency is to enlarge the uptakes still further when rebuilding.

(2) Fig. 3 shows that the large slag pockets have the plane of the bridge wall (separating the slag pocket from the regenerator) some distance in front of the nearest uptake. This is a good point favouring free-draughting conditions and more even flow between the two uptakes.

Calculation of a rough draught balance for the outgoing waste gases in the case of *G* furnace indicates that a draught of just over $\frac{1}{2}$ in. W.G. would be sufficient to exhaust the waste gases from the fuel quantity given on p. 239 P. Obviously there is an ample margin of draught with the available 2 in. W.G. and this ample margin will help towards the attainment of lengthy campaigns; on the other hand, careful draught control must be necessary.

With regard to performance, speakers at the Meeting stressed the very favourable metallurgical load of the Port Kembla furnaces compared with British practice. Whether the high output and low fuel consumption of these furnaces are due entirely to the light metallurgical load or whether the good design also plays a part is rather difficult to assess, particularly as there are no fixed furnaces of comparable capacity in Britain. There are not sufficient data given in the paper to permit of the evaluation of performance figures by the methods outlined in The Iron and Steel Institute's Symposium on Steelmaking.[1] However, the influence of the metallurgical load can be largely eliminated by considering the rate at which cold materials are melted, and Mr. Knight gives some data in Table XI. which enable one to make calculations for comparison. For Port Kembla heats *D*43 and *F*249 we have:

	*D*43.	*F*249.
Heat required to melt solid components of charge. Therms	1290	1164
Time from starting to charge till melt. Hr. . .	10·17	9·55
Therefore rate at which furnace supplies useful heat. Therms per hr.	126·8	121·8

The only available data for a British furnace working a similar size of heat are those published in The Iron and Steel Institute's Symposium (*loc. cit.*, pp. 132–133) referring to the Cargo Fleet tilting furnaces. The average of the data given for three heats gives results as follows:

Average heat required to melt solid charge . .	1106 therms
Average melting time	9·36 hr.
Therefore rate at which furnace supplies useful heat	118·2 therms per hr.

In this particular example there is little difference between the Australian and British furnaces as regards melting ability, and it

[1] *The Iron and Steel Institute*, 1938, *Special Report No.* 22, p. 390.

does look as if the high output of the Port Kembla plant is mainly due to favourable materials.

It is rather surprising that a greatly superior melting ability is not shown by the Port Kembla furnaces, considering their exceptionally good design. Probably the reason for this is that with hot-metal practice and deep baths the merits of these furnaces as regards good design, efficiency of combustion and high potential heat throughout in the melting chamber cannot be advantageously used. In hot-metal practice, for most of the operating time the heat input to the material is limited, not by what the flame can release, but by what the charge can take up, so that a keen furnace has to be held back. It is important to bear these limitations in mind, as, if a hot-metal furnace in Britain were rebuilt to the Port Kembla pattern, it might give no better results than a less advanced design. It would be very interesting to see what melting rates Port Kembla furnaces could attain when working the cold-metal process.

Mr. J. N. Kilby (Hon. Member of Council; Messrs. Richard Thomas & Co., Ltd., Scunthorpe, Lincs.) wrote: The outstanding features of the practice at the Port Kembla Works are the quality of the iron-bearing raw materials and the consequent type of hot metal transferred to the mixer and, later, from the mixer to the steel furnaces. With such raw materials and furnaces of such sound design and so generously proportioned, the output of steel per hour should be the highest, and with the minimum of fuel consumption. Regularity in feeding the steel furnace, both in tonnage and in quality of metal, and the subsequent important relationship to output and the resulting steel quality generally are two of the elementary but most important features in open-hearth furnace working.

The output of steel ingots per unit per hour always intrigues one, and very often causes a certain amount of worry. I well remember, even in my very early days, having to take many a rude jar when it was impressed upon me that English output per furnace was half what it was in Germany, but I am sorry to say that vital operative details were never submitted at the same time.

It has been my fortunate lot to operate open-hearth furnaces of all sizes and types, consuming every class of raw material and covering every quality of steel product. Therefore, I am taking the opportunity so well afforded to put on record a few of my views relative to basic open-hearth steel production, many of which have been expressed at metallurgical and other meetings over a long period of years.

In introducing these features of English practice, I do not wish for a moment to detract from the value of Mr. Knight's contribution, nor, so far as this is concerned, give anything but appreciation, and whilst he has not, for obvious reasons, given us any figures of cost, one can readily draw conclusions as to what they might be.

Long practice has proved the value of operating with low-

phosphorus iron (0·1% max.) as against basic iron containing 1·5–1·75% of phosphorus. The output of ingots is at least 40% in favour of the former, and where the charge is enriched with manganese this increase is greatly extended. Other factors being constant, hot-metal practice on phosphoric iron is at its lowest as regards both output and quality of material when the silicon and phosphorus are at their highest. As an example, consider two furnaces operating on 60–80% hot-metal practice, (*a*) working iron containing 0·6–0·9% of silicon and 1·2–1·4% of phosphorus, and (*b*) using iron with 1% or more of silicon and 1·4–1·8% of phosphorus; the output of (*a*) will be not less than 20% greater than that of (*b*).

As the slag ratio increases the output drops, not in proportion but increasingly, and the quality and yield of the product also fall very considerably.

Taking one works as a guide, the cost of ingot production in the two cases quoted above, based on a given percentage of pig iron, shows a difference of 10*s*. per ton and an ultimate mill yield of 5% in favour of (*a*).

Table A is an expression of corresponding results confirmed by long recording of results in practice, reduced to simple figures.

TABLE A.—*Influence of Slag Volume on Output of a 100-Ton Furnace.*

	Slag Volume. %.	Output. Tons.	Output Gain, Tons— By Slag Volume Effect.	Output Gain, Tons— By Time Effect.	
(*a*) .	25	100	...	...	Corresponding to 60–75% hot metal (phosphoric).
(*b*) .	20	120	15	5	
(*c*) .	15	140	30	10	
(*d*) .	10	170	45	25	Corresponding to Australian practice (manganiferous, low phosphorus).

Assuming a reasonable average figure for output from a 100-ton furnace operating on phosphoric pig iron under normal conditions to be 1250 tons per week, there would be no difficulty with the same melting capacity but using low-phosphoric iron and a consequent low slag ratio in attaining an output of 2000 tons.

Reaction Overflow Slags.—Over a period of years attempts have been made in Britain, by a combination of metallurgical and engineering expedients, to effect slag removal from fixed furnaces. I have yet to see results which confirm any regularity or effectiveness of this operation.

With the Australian conditions of high-manganese and low-phosphorus iron, the slag conditions, whilst exceptional to us, are

still readily understandable, and the resultant smooth working and effectiveness are natural. Also, there is nothing irregular or extraordinary in the use in Australia of silica as a reagent during conversion, although such would be prohibitive and impracticable in English basic open-hearth practice.

This paper on Australian practice on low-phosphorus material indicates that with the available raw materials in Britain the load on the open-hearth furnace can and should be lightened to the fullest extent possible by selective pig iron manufacture, and the abolition of mixers, which usually only touch the fringe of the good work which could be done if displaced by installations of what I would call "primary" furnaces of adequate capacity, *i.e.*, well above the steel furnace demand, which would ensure ample supplies of metal of consistently correct analysis at the right temperature, thereby fixing the ratio of fluxes for slag-making and conversion in the open-hearth furnace.

It is interesting to see that fixed furnaces operate so well even up to such a great capacity as that noted in the paper, and we have heard of even bigger tonnage furnaces in the United States of America. Such tonnages would become impossible with a phosphoric-iron load, and not only would primary-furnace operation have to come into the picture, but it would also be necessary for tilting steel furnaces to be seriously considered when lining up steel plant design.

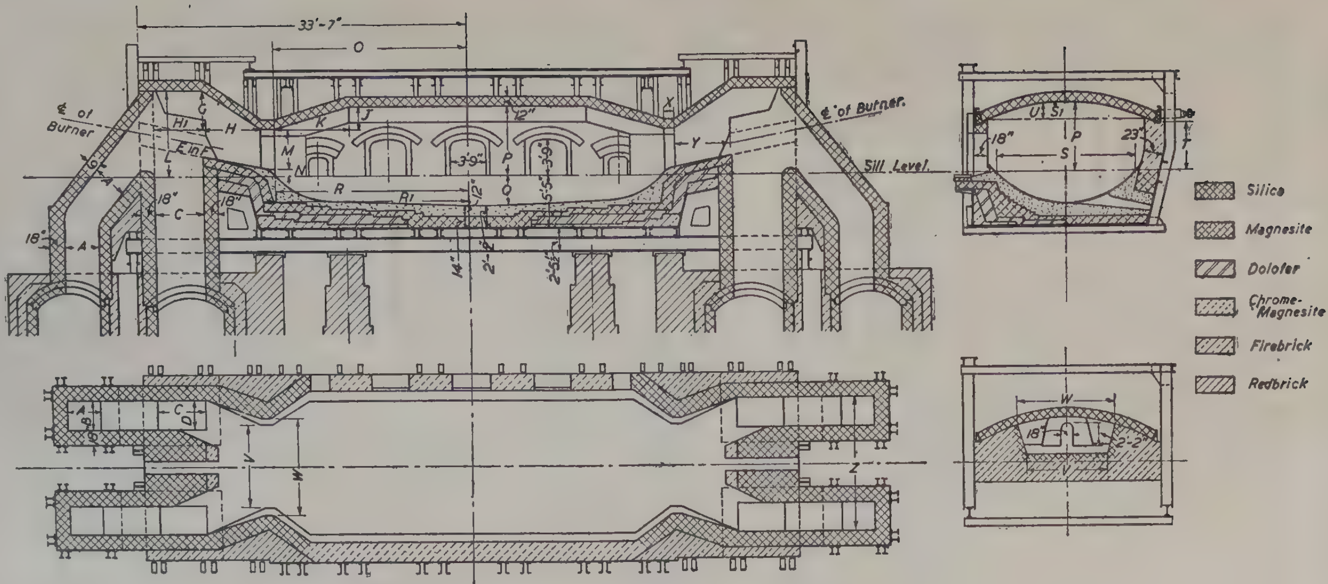
Furnace Design.—The principles of design of the furnaces, as shown in the paper, are good and indicate a generous approach to the problems usually met with in steel conversion.

We in England err on the mean side in our considerations of dimensional ratios to capacity, and it would be advantageous to be more generous when considering margins of safety and allowances to parts which age prematurely and determine not only the length of the seasonal campaign of a furnace but also the total furnace life, *i.e.*, from the time when the furnace is built to the time when it is totally rebuilt.

We have great room for improvement in steel plant layout and steel furnace design, covering the primary treatment of materials, the conversion and transference of steel and the disposal of slag and dirt to ensure shop balance and elasticity.

Development of the All-Basic Furnace.—After we have regularised the charge and the furnace dimensional ratios, the resistance of the steel furnace to fastest service conditions is ruled by the type and quality of the refractories employed. The improvement of basic refractories will certainly go ahead when conditions allow of full development.

Close practical experience and knowledge only can gauge the efficiency of repairs, fettling and care of a furnace and measure the consequent wide difference between the siliceous and basic construction of the furnace.



Air Uptake,	A x B	3'-6" x 3'-2"	Rise in Roof,	J in K	2'-3" in 8'-1"	P	7'-0"	T	4'-6¼"	V	8'-6"
" "	C x D	5'-0" x 3'-2"		L	8'-9"	Q	3'-3"	Larger Doors,	3'-9" x 3'-9"	W	10'-0"
Slope of Ramp,	E in F	3" in 12"		M	4'-3"	R	20'-0"	Small Doors,	2'-0" x 2'-0"	X	1'-6"
Rise in Ramp,	G in H	4'-0" in 5'-6"		N	6"	S	13'-6"	Rise in Roof, U.	1'-9"	Y	5'-9"
	H_1	5'-1"		O	20'-0"	S_1	16'-2"	R_1	21'-0"	Z	14'-0"

FIG. A.—Open-Hearth Furnace at Redbourn Works.

Even when obtaining moderate outputs the difference is great, but where large outputs are expected and the furnace has to be driven basic construction becomes imperative.

Actual experience only can gauge the physical and mental endurance required to drive a steel furnace and the efficiency required in the placing of the necessary fettling and repairs.

Continuous Working.—To obtain the maximum output and use of the all-basic furnace, it is necessary to work continuously as far as possible through the week-end, *i.e.*, the furnace should not be stopped except for an essential repair which necessitates the gas being taken off. The peeling of the roof and lining structure is thereby minimised.

The war, of course, stopped our activities in connection with the development of the all-basic furnace. Briefly, so far as we had gone, our conclusions were that when materials are available, we shall proceed with the development from the point where we left off, and we shall attempt to make the campaign of the furnace as continuous as possible; then our gain should be not less than 25% in increased output, based on a normal working week, and considerably greater if we are permitted to operate with no week-end break.

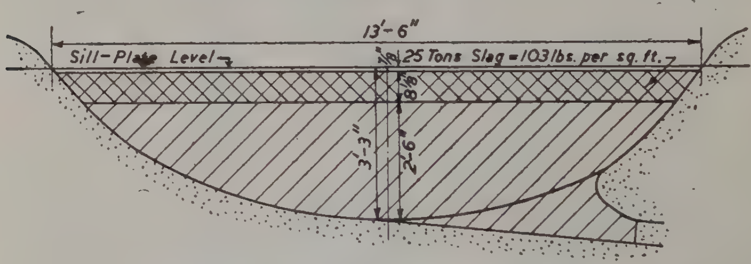


Fig. B.—Section through Bath of 100-Ton Open-Hearth Furnace.

Depth of Bath.—Over many years' practice I have often heard references to the depth of bath. The Australian furnaces are not particularly deep, considering their working conditions, *viz.*, good raw materials, intense reactions and small slag volume. On large furnaces an increase of the depth by 6–9 in. does not slow up operations, but, on the contrary, is an advantage, viewed from every angle. In England, we are apt to squeeze our open-hearth furnace capacity. As the furnace becomes larger structural difficulties and the reliability of the roof become highly important. I know of no rule which determines the most efficient depth of hearth, and I believe we are led a good deal by tradition.

Under the conditions that the paper describes and with the fettling materials at the author's disposal, I do not think that the depth of the furnaces should be stressed particularly, but if a steel furnace is going to keep a good dimensional ratio for very

heavy tonnages, the depth of hearth must increase out of proportion to the usual standard based upon small-furnace practice, and I do not foresee any " muffling " effect on operation and output if carried out within reason.

The main feature is a physical one, *i.e.*, the fettling of the furnace, and as the depth of hearth, particularly on a fixed furnace, is a consideration, this has to be borne in mind.

Fig. A shows the lines of development on open-hearth furnaces at Redbourn Works.

In order to illustrate the bulk effect on the hearth area of high

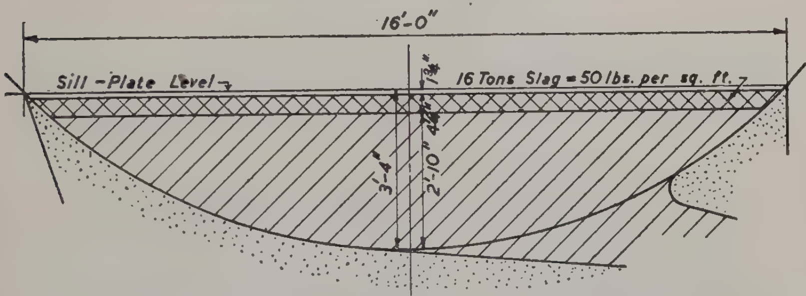


FIG. C.—Section through Bath of 230-Ton Open-Hearth Furnace (Port Kembla).

and low slag ratios, Fig. B, a section through the bath of a 100-ton open-hearth furnace, and Fig. C, a similar section through the 230-ton Port Kembla open-hearth furnace, have been prepared. In them the slag volume and depth are shown in relation to the bath of steel, taken on a line through the centre of the furnace. In Fig. B there is an 8-in. blanket of phosphoric slow-refining slag on 30 in. of steel; in Fig. C (Port Kembla) there is just over 4 in. of non-phosphoric highly basic rapid-working slag on 34 in. of steel.

It is regretted that the author's reply has not been received at the time of going to press.

A CRITICAL CONSIDERATION OF SOME APPLICATIONS OF THE SPECTROGRAPH TO STEELWORKS ANALYSIS.[1]

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(Figs. 1 to 5 = Plates VI. to IX.)

Paper No. 18/1943 *of the Committee on the Heterogeneity of Steel Ingots (submitted by Dr. W. H. Hatfield, F.R.S.).*

Summary.

Developments in the technique and application of spectrographic methods to quantitative analysis have been rapid in recent years. In regard to steel, F. G. Barker in 1939 (*Journal of The Iron and Steel Institute*, 1939, No. I., pp. 211P–245P) discussed and laid down a detailed procedure for the application of the spectrograph to low-alloy materials. The present authors have studied in considerable detail the application of such a method to routine steelworks analysis.

It is pointed out that, at the present stage of development, errors in spectrographic analysis are often considerably greater than those of the alternative chemical procedure and possible advantages in speed or economy can only be exploited where the magnitude of the errors, coupled with the wideness of the melting specifications, makes their toleration possible. To explore the possibilities the whole technique has been studied and various precautions and modifications have been introduced to minimise maximum errors without rendering the process impracticable or uneconomic.

It is emphasised that the highest accuracy is to be expected where large numbers of casts are melted to a single specification, permitting concentration on a relatively narrow range of composition. In the authors' work this has been possible in the case of two high-alloy steels, and many thousands of casts have been successfully analysed. Full details of the technique, the lines used, and the results obtained are given.

In addition, working details and typical results are given for the case of mixed batches of low-alloy steels. Although the rather lower accuracy attainable under such conditions, together with, in general, much narrower melting specifications, has so far prevented the successful large-scale application of this procedure by the authors to the routine works analysis of such low-alloy steels, considerable use has been made of the method in special cases. Moreover, conditions in individual works vary, and where they are such as to permit the concentration of a more limited range of compositions on individual plates, higher accuracy and more successful applications are to be expected for these materials also. It is hoped that the indications and data given will assist in such development.

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[1] Received August 31, 1942. This paper is published by authority of the Committee on the Heterogeneity of Steel Ingots. The views expressed in it are the authors', and are not necessarily endorsed by the Committee as a body.

Introduction.

Chemical analysis has in many directions reached such a high standard of speed and accuracy that the merits of any alternative procedure must receive the most careful scrutiny if disappointment is to be avoided. This is certainly true in the case of much steel analysis.

In recent years the application of the spectrograph to quantitative analysis, as an alternative to the more normal chemical methods, has been developed and explored with increasing intensity, and many papers and articles have appeared dealing with its use in the most diverse fields. Under such conditions of rapid development some suggested applications of the method to fields where, in its present stage, it must prove inferior to existing chemical procedure are to be expected. Nevertheless, there are directions in which the spectrographic method has proved of very material value in steel analysis, and it is hoped that the present critical consideration of the application of the process to the analysis of a variety of alloy steels will help in defining the present limits of usefulness, besides suggesting lines of further development.

A good deal of the spectrographic work on steel carried out in America has centred round the development of methods for the rapid production of pass-test analyses, as, for example, in the work of Vincent and Sawyer at Michigan University, and its commercial application by the Ford Motor Company.[1] Success in this sphere demands careful preliminary study with subsequent intensive organisation and team work. It is also necessary that conditions should be suitable in regard to the variety of steels, the number and rate of delivery of samples, and the required limits of accuracy. Given these, improvement is claimed over normal chemical procedure.

In Great Britain, Barker [2] has dealt with the subject from the alternative angle of the general routine analysis of miscellaneous samples of low-alloy and carbon steels, of composition ranging up to $4\frac{1}{2}\%$ of nickel, $1{\cdot}6\%$ of chromium, 2% of manganese, $0{\cdot}7\%$ of molybdenum and $0{\cdot}3\%$ of silicon and vanadium. It was on the basis of the detailed discussion of the method and procedure given in Barker's paper that the authors commenced their study of the application of the spectrographic method to steelworks analysis. In the initial stages the work was therefore mainly concerned with carbon and low-alloy steels, but practical development was eventually

[1] H. B. Vincent and R. A. Sawyer, "Routine Spectroscopic Analysis in Ford Motor Co. Foundry," *Metal Progress*, 1939, vol. 36, July, pp. 35–39; also *Proceedings of the Seventh Summer Conference on Spectroscopy and Its Applications* (Massachusetts Institute of Technology), 1939, pp. 16–18.

[2] F. G. Barker, "Some Applications of the Spectrograph to the Quantitative Analysis of Ferrous and Non-Ferrous Metals," *Journal of The Iron and Steel Institute*, 1939, No. I., pp. 211 P–245 P.

largely concentrated on certain higher-alloy steels, for reasons indicated in later Sections of the present paper.

Apparatus used and General Principles of the Method.

There are now various types of spectrographic apparatus on the market, including prism and grating spectrographs and recording and non-recording photometers. For the work here described the authors have used essentially the same apparatus as that very fully described in Barker's paper (*loc. cit.*), consisting of Hilger large quartz spectrographs (Fig. 1), Hilger non-recording photo-electric microphotometers (Fig. 2), and the Judd Lewis comparator for the general qualitative comparison and examination of plates and preliminary work on line selection.

The general principles of spectrographic technique are now widely understood. Briefly, in the work here described, the specimen to be analysed is used as one electrode, and a pointed graphite rod as the other. Passage of current from a 15,000-V. transformer across the gap between the electrodes vapourises some of the steel and causes it to emit light of wave-lengths which are characteristic of the particular elements present. The spectrograph splits up the composite light so emitted, giving a series of lines on a photographic plate, each line corresponding in position to light of a given wave-length and in blackness to the intensity of the light of that particular wave-length. The intensity of light of any selected wave-lengths can then be determined from the density of the corresponding line on the photographic plate, this density being measured by the photo-electric photometer. The results of such determinations are then related to the composition of the sample by means of curves based on the response of " standard " samples of known chemical analysis under similar conditions.

In practice various corrections are required, and a first correction for fluctuation in the general density of the spectra is made by plotting, not the simple intensity or log. intensity against composition, but the log. ratio of the photometer readings for the selected line of the element in question and a suitable comparison iron line,[1] the iron line being used as a measure of the general relative density of the spectrum under consideration.

With careful work, and without further correction, it will usually be found that most of the errors are within $\pm 5\%$ of the amount of the element present, but occasional errors up to as much as $\pm 10\%$ will occur. This is well brought out by Table XIII. of Barker's paper (*loc. cit.*), in which the errors on fifty casts of nickel-chromium-molybdenum steel are summarised, using three spectra for each determination. Thus, for example, occasional errors of as much as $\pm 0{\cdot}25\%$ on $2{\cdot}5$–$3{\cdot}5\%$ nickel are found. Errors of this magnitude

[1] Some workers plot log. ratios against log. composition for further simplification of line form, but the authors have not found any practical advantage from this in their work.

are, of course, too high for analytical work with steel melted to narrow specification limits if the melting tolerance is not to be entirely absorbed by the spectrographic error. In passing, it may be pointed out that the matter of most practical interest is not the carefully computed mean error for the process but the magnitude and frequency of the maximum errors likely to be encountered. For successful application to routine analysis it is evident that every endeavour must be made to reduce these maximum errors and to confine the use of the method to fields where the residual liability to error can be tolerated.

Before describing the technique employed and the results obtained in the authors' work with different types of steel, it will be desirable at this stage to consider in some detail a number of sources of error and means adopted for reducing their effects.

Detailed Consideration of Technique in Relation to Sources of Error.

Variations Introduced during the Taking of Spectra.

Variations in the brightness and stability of the spark can easily arise during the taking of spectra, with consequent alteration of the effective exposure of the photographic plate, as well as the possible introduction of variations in the relative intensities of the light giving rise to the various lines. While it is often possible in practice to offset such changes more or less completely by applying suitable corrections, it is obviously desirable that they should be minimised as far as possible at the source.

Stabilisation of the primary voltage applied to the transformer is an obvious precaution in this connection, but in the authors' experience reasonable fluctuations here are not of great importance. The chief causes of variation are defects in the surface of the steel or graphite electrode points, causing unsteady sparking, and inaccuracy in setting the gap between the two electrodes, variations in the width of which seriously modify the spark intensity. This question of the size of gap is of very considerable importance, and it should always be set with the greatest possible accuracy consistent with the required speed of working.

With the type of small ingots employed in the authors' work, they have found an optical projection method the most generally satisfactory for measuring the size of the gap. Some workers can obtain very good results with a gauge plate, but in most cases the authors have found that the optical method gives greater uniformity between operators, besides avoiding damage to the point of the graphite electrode. The general arrangement of the sample and projection lamp is shown in Fig. 1.

The influence of variation in the gap width has been studied in detail for a number of steels, and the type of results obtained is illustrated by the values given in Table I., which relate to a high

TABLE I.—*Rotating Disc and Electrode Gap Experiments on Steel A.*

Silicon.

Disc Experiments.			
Disc opening	⅛	½	¾
Fe line reading. Cm.	30	12	7
Total correction required on log. ratio Si/Fe	+0·114	...	−0·043
Photo-correction	+0·119	...	−0·048
Difference	−0·005	...	+0·005

Gap-Width Experiments.				
Gap width. Mm.	1	2	3	4
Fe line reading. Cm.	27	13	9	8
Total correction required on log. ratio Si/Fe	+0·128	...	−0·008	−0·038
Photo-correction	+0·073	...	−0·018	−0·023
Difference	+0·055	...	+0·010	+0·015

Manganese.

Disc Experiments.			
Disc opening	⅛	½	¾
Fe line reading. Cm.	33	12	6
Total correction required on log. ratio Mn/Fe	−0·016	...	+0·001
Photo-correction	−0·021	...	+0·006
Difference	+0·005	...	−0·005

Gap-Width Experiments.				
Gap width. Mm.	1	2	3	4
Fe line reading. Cm.	27	11	6	5
Total correction required on log. ratio Mn/Fe	−0·032	...	−0·004	+0·066
Photo-correction	−0·027	...	+0·001	+0·016
Difference	−0·005	...	−0·005	+0·050

Chromium.

Disc Experiments.			
Disc opening	⅛	½	¾
Fe line reading. Cm.	36	14	7
Total correction required on log. ratio Cr/Fe	−0·169	...	+0·031
Photo-correction	−0·179	...	+0·031
Difference	+0·010	...	0·000

Gap-Width Experiments.				
Gap width. Mm.	1	2	3	4
Fe line reading. Cm.	30	14	8	8
Total correction required on log. ratio Cr/Fe	−0·139	...	+0·044	+0·105
Photo-correction	−0·134	...	+0·034	+0·055
Difference	−0·005	...	+0·010	+0·050

Nickel.

Disc Experiments.			
Disc opening	⅛	½	¾
Fe line reading. Cm.	40	18	10
Total correction required on log. ratio Ni/Fe	−0·082	...	+0·042
Photo-correction	−0·082	...	+0·037
Difference	0·000	...	+0·005

Gap-Width Experiments.				
Gap width. Mm.	1	2	3	4
Fe line reading. Cm.	33	17	9	8
Total correction required on log. ratio Ni/Fe	−0·057	...	+0·011	+0·001
Photo-correction	−0·077	...	+0·016	+0·006
Difference	+0·020	...	−0·005	−0·005

Vanadium.

Disc Experiments.			
Disc opening	⅛	½	¾
Fe line reading. Cm.	39	21	13
Total correction required on log. ratio V/Fe	−0·164	...	+0·026
Photo-correction	−0·164	...	+0·036
Difference	0·000	...	−0·010

Gap-Width Experiments.				
Gap width. Mm.	1	2	3	4
Fe line reading. Cm.	35	20	13	13
Total correction required on log. ratio V/Fe	−0·120	...	+0·042	+0·097
Photo-correction	−0·145	...	+0·027	+0·067
Difference	+0·025	...	+0·015	+0·030

manganese-nickel-chromium-vanadium steel with which the authors have done a great deal of work and which will be referred to here as steel *A*.[1]

It is evident that alteration in the gap width can have two effects. In the first place it modifies the intensity of the spark and therefore the overall intensity of the light emitted. This change can be allowed for by using the characteristic response curve of the photographic plate to convert the photometer readings into terms directly related to the actual light intensity. The log. ratio for the element line and the iron comparison line should then remain unaltered by the change in overall brightness. The successful application of such "photo-correction" is illustrated by the results of the disc experiments in Table I. These were obtained with a constant gap width and sparking time, but with a varying effective time of exposure introduced by the use of rotating discs with open sectors of varying sizes. In this way the only variation was in the effective exposure, which for this purpose has the same effect as a variation in the overall intensity of the light with a fixed exposure. It will be seen that the photo-corrected log. ratios in no case differed from the normal (half-disc opening) by more than $\pm 0{\cdot}010$, which can be taken as indicating the limiting experimental error.

In addition to the overall intensity change, however, there may be appreciable changes in the relative intensities of the lines for the various elements induced by modification of the gap width. This is illustrated in the remainder of the Table, where the results are given for tests in which the gap width was modified and the time of exposure kept constant. Comparison of the iron line readings shows that the density range covered was similar to that in the disc experiments, but photo-correction no longer removes all the variability; in fact, there are large differences between the 3- and 4-mm. gap results with very little change in the iron line intensity. In this latter connection it is interesting to note that under the authors' conditions of excitation the spark itself becomes much more erratic in passing from 3 to 4 mm., wandering about and producing a number of small craters on the specimen instead of essentially one central crater.

It is evident from the results that the most stable region for the gap width for steel *A* is between 2 mm. and 3 mm., and, similar results having been obtained for the other steels tested, the authors have standardised on a 2½-mm. gap as being the width least likely to introduce variations from slight divergences in gap adjustment.

The Use of Duplicate Spectra.

The authors' normal procedure is to use the average values from two spectra for the analysis of each sample. If it were economically

[1] The actual composition of the sample used in this series of experiments was :

Si. %.	Mn. %.	Cr. %.	Ni. %.	V. %.
0·77	5·66	5·13	12·04	0·31

FIG. 1.—General Arrangement of Spectrographs, showing type of sample and method of adjustment and support during sparking.

[*Shirley and Elliott.*

[*To face p.* 304 P.

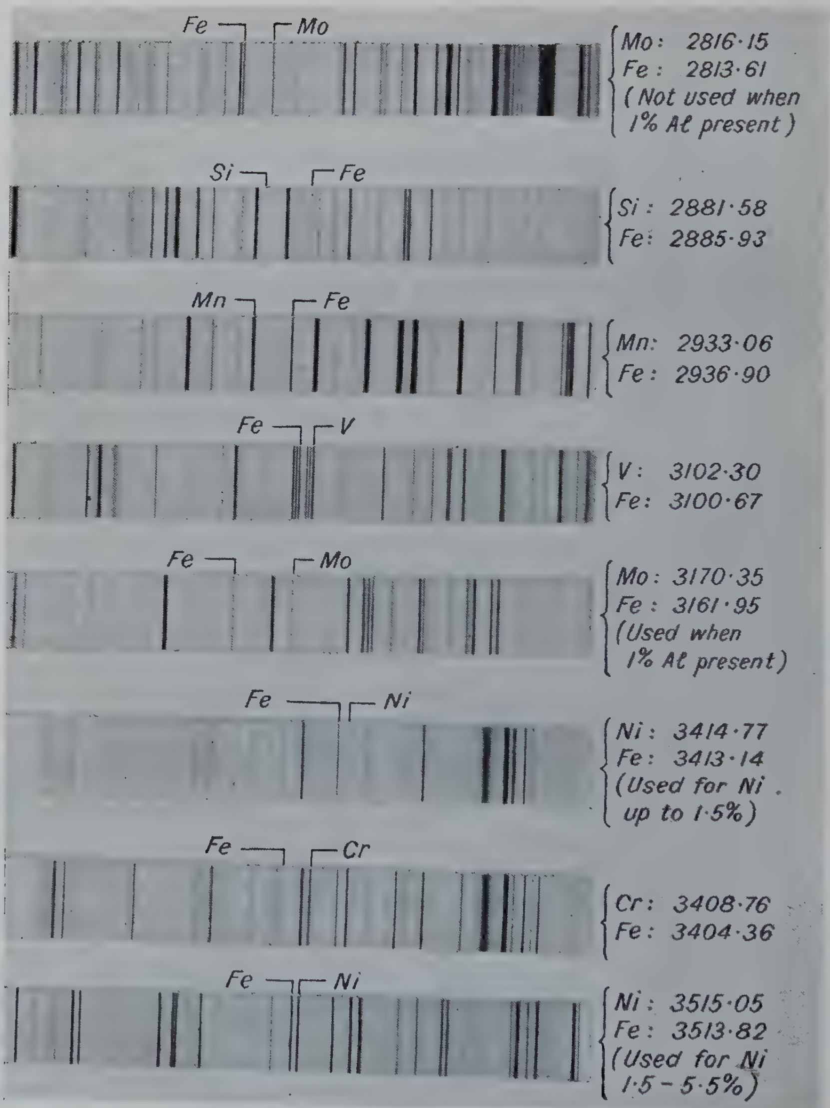

FIG. 5.—Lines used for Low-Alloy Steels.

[*Shirley and Elliott.*

[*To face p.* 305 P.

possible to take and read, say, six or more spectra in each case, a very close approximation to the true analysis would be obtained, even in the case of elements present in amounts up to 20%. In most cases, however, it is not practicable to consider the use of more than two spectra for each sample, but this duplication is definitely worth while, permitting immediate checking of doubtful results besides giving some general increase in accuracy.

To obtain the fullest benefit from this checking, and in the interests of speed in subsequent calculations, the authors arrange the duplicate spectra adjacent to one another, although it is arguable from the point of view of plate and processing variables that it would be better to put them apart or even on different plates. The method has an additional obvious advantage in plate economy in the case of partly filled plates.

Although only two spectra are used for each sample, each spectrum is in fact a composite of two or three superimposed exposures taken at different points on the surface of the specimen. As pointed out by Barker (*loc. cit.*, p. 242P), this procedure tends to minimise segregation effects; it also reduces errors resulting from inaccuracy in setting up specimens and electrodes and any other errors arising from variations introduced during the taking of the spectra.

The Selection of Line Pairs.

The ideal is to use only pairs of lines which are truly homologous, occur close together, and are of similar density. These lines would be so equally influenced by variations in the conditions and technique that such variability would have the least possible effect on the results. Unfortunately, search through the complex spectra of the higher-alloy steels often fails to discover such perfectly adjusted line pairs, and recourse must be had to those giving greatest accuracy under practical working conditions. The selection of the most suitable lines is a part of the work calling for patience and care, but it is an essential preliminary to all new work, the accuracy of which, within the limits of the lines available, is very largely dependent on this initial selection of the working lines.

The authors' work on plate calibration and line selection has been constantly referenced to the iron arc spectrum, using the Hilger map for identification of the lines, while extensive use has been made of Harrison's Wave-Length Tables[1] to confirm and identify lines of the other elements. In this way and by the comparison of spectra prepared from samples approximating to the types of steel under consideration, but showing fairly wide differences in the content of individual elements, it has been possible to select visually

[1] By far the best available collection of data on this important subject and containing particulars of more than 100,000 lines. (Published by John Wiley, Inc., and Chapman & Hall, Ltd., 1939.)

in the Judd Lewis comparator the most hopeful lines for final study in the photometer.

The ultimate choice of lines has been based upon the degree to which they fulfil the following criteria:

(a) *Satisfactory Density.*—This is complicated by the fact that the whole of the lines required from a given plate must be such as to come within the useful photographic range. The final exposure and development must usually be something of a compromise between the demands of the best lines found, and in some cases it may be necessary to reject otherwise suitable lines because they cannot by any means be brought to a suitable density coincident with satisfactory results with other essential lines. The authors have used lines with densities corresponding to between 3-cm. and 40-cm. deflections on the photometer scale. A rather narrower range than this is usually considered desirable, but cannot always be attained in practice when dealing with higher-alloy steels.

(b) *Sensitivity.*—This can be judged roughly in the Judd Lewis comparator by visual examination of line-density changes for samples showing appreciable differences of alloy content in the neighbourhood of the range under consideration, as indicated above.

(c) *Availability of Suitable Iron Line.*—The comparison iron line should preferably be close to the alloy element line and of similar density. This minimises the effects of plate and processing variables and avoids loss of time in the photometry in the continual movement of the plate to and fro in passing from one line to the other.

(d) *Freedom from Interference by Other Lines.*—Incomplete resolution between a line of some other element and a line of the element under examination will usually prevent its use. Thus, the molybdenum line 2816·15, which, in low-alloy steels, the authors normally prefer to the line 3170·347 given by Barker (*loc. cit.*), cannot be used with steels containing appreciable amounts of aluminium because of interference by the 2816·18 line of this element. On the other hand, there are cases where overlapping of a weak iron line can be tolerated, as, for example, in the case of the molybdenum line 3170·347, which the authors still use for steels such as those containing 0·2% of molybdenum in the presence of 1% of aluminium, although it is overlapped by the iron line 3170·346.

Plate Characteristics.

Local irregularities in the emulsion, spots, scratches, abrasion marks, and a tendency to staining are all objectionable, and plates and methods of processing should as far as possible be chosen so as to minimise these effects. In so far as some minor imperfections are almost certain to be present in the finished plates, the authors find it very useful to employ only about a third of the $1\frac{1}{2}$-mm. length of the lines. They are then often able to avoid the effects of local damage or defects and obtain satisfactory readings from

spectra which would otherwise require retaking, by selecting an undamaged portion for measurement. Normally the middle portions are read.

In general the plates should be chosen to give as high a contrast as possible consistent with satisfactory simultaneous rendering of the lightest and darkest lines required. The speed should be such as to require a reasonable exposure. Very short exposures exaggerate timing inaccuracies and the effects of any momentary instability of the spark, and the authors endeavour to keep within the 10–25 sec. range. Longer exposures normally mean unnecessary waste of time.

The Method of Processing the Plates.

It is clearly desirable that development should be both uniform and reproducible, and it is often considered that frequent or continuous agitation of the solution is advantageous in this connection. Experimenting with the development of uniformly fogged plates, the authors found it not at all easy to obtain uniform development, particularly with plates having thin emulsions which process more rapidly than, say, the "Zenith" plates originally used by Barker. The authors tried many variations in procedure, and, bearing in mind that the method adopted should be simple and easily reproducible by different workers, eventually standardised a method in which the plate is lowered horizontally into the solution and squeegeed lightly with a flat rubber squeegee for a few seconds, agitated in a random manner for a few more seconds and then left without further agitation until development is completed.

In deciding on the type of developing solution to be used and the time and temperature, it must be borne in mind that all these, together with the type of plate, influence the density and contrast of the image obtained, and a suitable combination must be found by experience which will give the maximum contrast consistent with satisfactory reading of the required lines. Standardisation should be assisted by the adoption of some simple precaution to keep the temperature of the developer constant.

Fixing, hardening and washing of the plates are not critical, and can easily be carried out in ten minutes or less if required. Care must be taken to avoid uneven drying, as this will lead to marks on the plates, and the use of a viscose sponge to remove surplus moisture, followed by drying in a current of warm dust-free air, is desirable.

Adjustment for Varying Speed of Plates.

A decrease in the speed of plates is to be expected with age, and variation has been found in practice between boxes from a single delivery under the present wartime conditions.

In cases where the lines to be measured are of widely differing densities, covering most of the available range of the plate, some

modification in procedure must be introduced to correct for such variations in speed.

Modification of exposure is the most obvious method for modifying density, but unfortunately this is liable to introduce an appreciable modification in the log.-ratio/concentration relationships for the various elements, and, while the use of standard samples permits a correction to be applied for this, it is considered better to avoid any considerable modification of the exposure as far as possible.

In Table II. results are given illustrating the magnitude of the changes arising from modified exposure in the case of steel *A*.

TABLE II.—*Influence of Length of Sparking Time on Log. Ratios for Steel* A.

Sparking Time. Sec.	Silicon.		Manganese.		Chromium.		Nickel.		Vanadium.	
	Log Ratio.	Apparent Content.	Log Ratio.	Apparent Content.	Log Ratio.	Apparent Content.	Log Ratio.	Apparent Content.	Log Ratio.	Apparent Content.
8	0·193	0·76	0·994	5·4	0·711	5·0	0·861	12·25	0·660	0·36
10	0·193	0·76	0·003	5·3	0·710	5·0	0·858	12·25	0·689	0·33
12	0·191	(0·77)	0·002	(5·29)	0·716	(4·95)	0·860	(12·26)	0·692	(0·33)
14	0·192	0·77	0·011	5·25	0·727	4·8	0·861	12·25	0·715	0·32
16	0·193	0·76	0·010	5·25	0·735	4·7	0·860	12·25	0·725	0·30
18	0·187	0·78	0·010	5·25	0·738	4·65	0·858	12·25	0·725	0·30

The values given for the log. ratios are the means of six spectra from two sets of three from each of two plates, and have been photo-corrected by means of the characteristic curves of the plate used. The apparent composition figures have been read from the

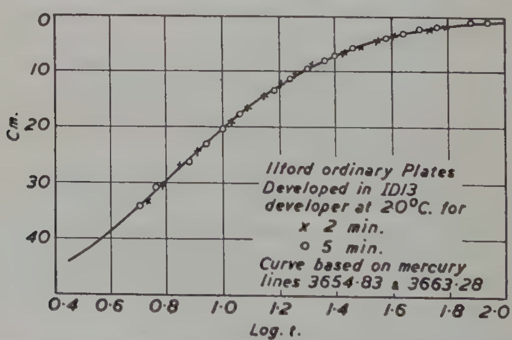

FIG. 6.—Stability of Form of Characteristic Curve with Varying Time of Development.

usual curves, using the normal 12-sec. exposure as the standard. With this steel minor variations in exposure are evidently unlikely to lead to serious errors if standard samples are used to check the

extent of the variations, but the variation is considerable for chromium and vanadium with the full 50% increase in exposure to 18 sec.

Alternatively, adjustment may be effected by variation of the time of development. Under the authors' conditions they have found so close a correspondence in the shape of the characteristic curves for development times between two and four minutes that there is no need for any modification over this range. This similarity in response is illustrated in Fig. 6 where calibration points for 2-min. and 5-min. development of Ilford Ordinary plates in *ID*13 developer at 20° C. are superimposed on a standard curve.[1] The actual readings obtained are given in Table III.

TABLE III.—*Influence of Time of Development on Form of Characteristic Curve.*

Exposure. Sec.	Log. Exposure.	2 min. Development.		5 min. Development.	
		Hg Line 3654·83.	Hg Line 3663·28.	Hg Line 3654·83.	Hg Line 3663·28.
50	1·70	1·0	1·15	0·55	0·65
30	1·48	2·05	2·55	1·05	1·25
20	1·30	3·85	4·65	2·0	2·55
15	1·18	6·0	6·85	3·45	4·0
10	1·00	8·95	10·55	6·05	7·3
8	0·90	12·45	14·6	8·3	9·85
6	0·78	16·7	19·25	11·3	14·0
4	0·60	24·4	27·05	18·0	20·5
3	0·48	30·85	33·65	23·3	26·55
2	0·30	...	...	31·25	35·75
Correction factor applied to log. exposure in Fig. 6.*		+0·31	+0·25	+0·46	+0·40

* The empirical correction is applied to bring the four sets of results on to the standard curve, since a difference of development time, the speed of the particular plate used and the intensity of the light used all displace the curve horizontally.

When dealing with old plates a practical limit to this form of correction may be reached earlier, owing to staining tendencies in the *ID*13 developer with prolonged development, but within the limits of its practical applicability this method of control has proved most valuable.

Photometry.

The employment of pairs of lines of similar, medium density is ideal photometrically as well as photographically, but, as already

[1] Details of the method used to obtain these readings are given in the later Section on the interpretation of results.

explained, is often impracticable. The greater the divergence from this ideal the greater is the care needed to ensure satisfactory density ratios.

Dense lines give small deflections on the photometer, and with them maintenance of a steady galvanometer zero is of special importance, any fluctuations then having a maximum influence on the readings. The need for steadiness of photometric conditions is emphasised when dealing with lines of divergent density.

With the type of photometer used it is at all times necessary to ensure accurate focusing of the line image at the photometer slit. Variations in plate thickness or flatness can appreciably affect the focusing over different areas of a plate, with considerable influence on the log. ratios, unless it is corrected. Fortunately, a ready check exists in the absence of movement of the properly focused image when the spherical lens used for viewing the lines is swung away for reading. Experienced operators acquire the ability to observe and correct the focus with certainty and with very little loss of time.

The use of adjacent duplicate spectra is of considerable value in the photometry in drawing immediate attention to reading errors. All divergences between duplicates beyond limits fixed by experience are checked by rereading and, if necessary, retaking. The amount of the permitted divergence depends on the sensitivity of the line read, since this alters the magnitude of the analytical errors involved. In general, it may be taken that the log. ratios for duplicates should not differ by more than 0·020 with any element, and closer agreement should be sought with the less sensitive lines.

Fatigue of the operator is liable to affect speed and accuracy in photometry, but average speeds of 80–100 line pairs per hour, including all necessary checking, are quite consistent with continuous accuracy, and appreciably higher speeds can be, and are, attained over shorter periods. Operational fatigue can be reduced by a system of rotation, avoiding long periods of continuous reading for a single operator. To this end the authors' assistants are grouped in teams of three, one exposing and developing a plate while the other two read the previous plate. Of these latter, one operates the photometer while the other writes down the readings and calculates the log. ratios. Interchange of duties at the photometer is arranged at the completion of the reading of each element. In this way, fatigue is very considerably reduced.

Correction for Photographic Density.

As already indicated, a first correction for varying spectral density is applied by plotting the log. ratios of photometer readings for the unknown element lines to those of suitable comparison iron lines. This simple treatment, however, leaves out of account the influence of the non-linearity of the characteristic log.-intensity/density curve of the photographic plate.

Examination of a large series of preliminary results showed that a distinct improvement in accuracy was possible by the application of empirical corrections, the magnitude of which was decided by the individual densities of the spectra, as indicated by the photometer readings for the comparison iron lines.

To apply such corrections in practice where experience indicated, say, a correction of 0·005 per cm. divergence of photometer reading, this amount would be added to or subtracted from the log. ratio for every centimetre by which the comparison iron line differed from the average in either direction. While not strictly accurate, this empirical procedure did provide a definite improvement in accuracy for not too great density fluctuations. The corrections used never exceeded 0·010 per cm., and are well illustrated by those employed in the early work with steel *A*, as follows :

Silicon . .	+0·005	per 1 cm. decrease in comparison iron line reading.
Manganese . .	+0·003	
Chromium . .	+0·008	
Nickel . . .	+0·005	
Vanadium . .	+0·005	

In spite of the usefulness of such empirical corrections, it is obvious that for lines of density corresponding to some portions of the characteristic curve results obtained in this way will not be as accurate as those given by properly evaluated corrections, based on the experimentally determined log.-intensity/density curve for the plates and conditions concerned. Eventually, therefore, the authors changed over to this latter procedure, thereby obtaining increased speed of calculation, in addition to an improvement in the general accuracy of correction.

The method adopted for plate calibration was based on the use of a 125-watt "Mercra" ultra-violet lamp. With this lamp in the normal sparking position, exposures at suitable intervals between one and a hundred seconds are usually satisfactory. Density measurements are made on the mercury lines 3654·83 and 3663·28. The characteristic curve is then plotted as log. time against an inverted scale of photometer readings (since these are a direct measure of transmission, not of density). A typical curve has already been illustrated in Fig. 6.

Although the position of the curve with respect to the log. time axis varies with the speed of the individual plate the authors have found the shape to remain very constant for a given type of plate over the range normally used (3 cm. to 40 cm. on the galvanometer scale, with 50 cm. as clear-glass reading). Constancy with age is well illustrated by Fig. 7, in which are shown results obtained with two Kodak *B*40 plates from the same batch, one exposed three days after receipt and developed for 2 min. in *ID*13 developer at 20° C., and the other sixteen months later, using 3 min. development. The similarity of form of the two curves is clearly shown by the

crosses representing results from the latter plate superimposed on the curve obtained from the former.

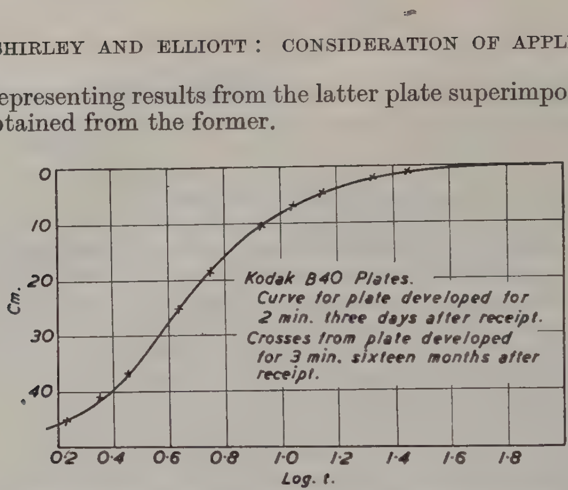

FIG. 7.—Stability of Form of Characteristic Curve with Age of Plates.

In view of this constancy of form with age, and even from batch to batch of a given type of plate, the authors have found it possible in the interests of speed and simplicity of working to convert the standard curves into tabulated series of log. intensity values, as illustrated in Table IV., which shows a portion of one such table.

TABLE IV.—*Illustration of Part of a Working Table Prepared from Log. Intensity Curve.*

Cm.	Log I.	Cm.	Log I.	Cm.	Log I.	Cm.	Log I.	Cm.	Log I.
6·0		6·9		8·8	0·340	9·7	0·305	11·6	
6·05	0·460	6·95	0·415	8·85		9·75		11·65	
6·1		7·0		8·9	0·335	9·8		11·7	0·235
6·15	0·455	7·05	0·410	8·95		9·85	0·300	11·75	
6·2		7·1		9·0		9·9		11·8	
6·25	0·450	7·15	0·405	9·05	0·330	9·95	0·295	11·85	0·230
6·3		7·2		9·1		11·0		11·9	
6·35	0·445	7·25		9·15		11·05		11·95	
6·4		7·3	0·400	9·2	0·325	11·1	0·255	12·0	
6·45	0·440	7·35		9·25		11·15		12·05	0·225
6·5		7·4	0·395	9·3		11·2		12·1	
6·55	0·435	7·45		9·35	0·320	11·25	0·250	12·15	
6·6		8·5		9·4		11·3		12·2	0·220
6·65	0·430	8·55		9·45	0·315	11·35		12·25	
6·7		8·6	0·350	9·5		11·4	0·245	12·3	
6·75	0·425	8·65		9·55		11·45		12·35	0·215
6·8		8·7	0·345	9·6	0·310	11·5		12·4	
6·85	0·420	8·75		9·65		11·55	0·240	12·45	

In this way it becomes a very simple matter for the operator to convert photometer readings into terms of log. intensity, which by simple subtraction give the required photo-corrected log. ratios for

use in plotting or reading from the log.-ratio/composition curves. Thus, for example, a 6·45-cm. reading of a manganese line is converted to 0·440 by the Table and an 8·6-cm. reading for the comparison iron line gives 0·350; subtraction of the former from the latter gives $\bar{1}$·910, which is the fully corrected log. ratio required. This is the most rapid method of working that the authors have tried, and although slight variation of the characteristic curve is to be expected from plate to plate and for lines of different wavelengths, this simple procedure has given most satisfactory results when combined with the use of standard samples, as described below.

The Use of "Standard" Samples.

When all the foregoing precautions have been taken there still occurs some variation in the composition curves from plate to plate, and a further increase in accuracy is possible by the use of "standard" samples. The authors use from two to four such samples on each plate, and these usually include one or two samples from recent casts to cover any day-to-day variation in the response of the material.[1] On the basis of the average behaviour of these standards small corrections are applied to the results read from the composition curves, or the curves themselves are moved relative to the axes.

Chemical Checks.

The recent standards referred to in the preceding paragraph are usually taken from the previous day's chemical checks. The number of such chemical analyses required to keep an effective check on general accuracy is a matter which must be decided by experience. Analysis of one sample in twenty should be sufficient when thorough experience has been gained, provided that this is not less than one analysis per day. For certain elements when the amount present is considerable and the line used is not very sensitive, provided that the chemical analysis does not involve any great trouble or loss of time, it may be found worth while to increase the number of chemical checks to, say, one in ten. This applies to nickel in the authors' work with steels *A* and *B*, for which a one in ten check permits rather closer correspondence to the chemical figures than would otherwise be the case.

The Influence of the Range of Composition.

The most satisfactory routine results from spectrographic analyses are to be expected where production arrangements make it possible to deal with a continuous flow of samples to one specifica-

[1] J. R. Handforth, H. W. Whymper and W. M. Boulton, "Spectrographic Analysis and its Application to Aluminium Alloys," *Metal Treatment*, 1939, vol. 5, Spring Issue, pp. 3–12.

tion. Individual plates can then be arranged to contain only a single type of steel, and the limited portion of the composition/log.-ratio curves required can generally be represented as straight lines. The small number of standards required then have their maximum correcting efficiency, correction being satisfactorily applied by the simple addition of a constant difference to results read from fixed composition curves. This represents the conditions under which the authors have worked for many thousands of casts of the high-alloy steels *A* and *B*, detailed procedure for which is given later.

On the other hand, satisfactory application of the method to the routine analysis of low-alloy materials would, in the authors' case, demand the inclusion on individual plates of a wide variety of steels, with the result that four or five standards, at most, would have simultaneously to characterise the curves for five elements fluctuating independently over ranges, which for nickel could be as great as from 0·1% to 5·5% and for chromium from 0·05% to 3·5%. Moreover, the densities of the lines used will vary over very much wider limits than when dealing with a single type of steel. The highest possible accuracy is not to be expected under such conditions.

Typical results for low-alloy steels dealt with in this way are given in a later Section, but it may be said here that the difficulties indicated, coupled in many cases with narrow melting specifications, have, so far, prevented any large-scale application of the method to such steel in the authors' work. At the same time the technique developed has proved very useful in special cases, permitting the satisfactory analysis of individual samples in connection with which, for various reasons, chemical analysis has been impossible or less satisfactory.

Details of Working Procedure and Results for High-Alloy Steels *A* and *B*.

Having discussed the general principles underlying the authors' technique it remains to describe in detail the actual procedure followed and the results obtained for different types of steel. The greater part of the authors' routine work has been concerned with two high-alloy materials, typical analyses of which are:

	Steel *A*.	Steel *B*.
Silicon	0·9%	1·2%
Manganese	5·5%	0·5%
Chromium	5·0%	14·5%
Nickel	12·5%	12·5%
Vanadium	0·3%	...
Tungsten	...	3·0%

From a detailed preliminary study of the spectra of these materials line pairs were selected as indicated in Table V. and illustrated in Figs. 3 and 4.

Table V.—*Line Pairs Selected for Analysis of Steels* A *and* B.

Steel.	Silicon.	Manganese.	Chromium.	Nickel.	Vanadium.	Tungsten.
A	Si 2881·58 Fe 2875·34	Mn 3488·68 Fe 3490·57	Cr 3408·76 Fe 3407·46	Ni 3510·34 Fe 3497·84	V 3102·30 Fe 3100·67	... ...
B	Si 2881·58 Fe 2885·93	Mn 2933·06 Fe 2936·90	Cr 3391·43 Fe 3407·46	Ni 3510·34 Fe 3497·84	... ...	W 4008·75 Fe 4009·72

The steel samples used are in the form of small chill ingots approximately 3 in. long by 1¾ in. square. One long edge is ground to a flat about ¼ in. wide and filed to remove grinding marks. The specimens are mounted in a universal holder, permitting rapid movement in all directions, and both the sample and graphite electrode are adjusted optically to the correct position and separation by means of a projected image and gauge lines. The graphite rods used are 6½ mm. in dia. and have 80° points. They are separated from the steel sample by a distance of 2½ mm., and the spark gap is arranged at a fixed distance of 38 cm. from the slit.

A slit width of 0·015 mm. is employed, the height of the individual spectra being 1½ mm. The wave-length range covered on the plate is 2700 Å to 4300 Å.

Using a 15000-V. supply transformer, a condenser of 0·005 microfarad capacity and no added inductance, Ilford Ordinary plates are given two superimposed exposures of 12 sec. for steel *A* and 25 sec. for steel *B*. Similar exposures apply to Kodak *B*20 plates.

Two to four standards are used and samples are taken in duplicate to make up the thirty-four spectra comprising a full plate.

The development time is usually 2–3 min. using *ID*13 developer [1] at 20° C. for Ilford plates, and 4–5 min. in *D*19*b* developer [2] at 18° C. for the Kodak plates. Three hundred millilitres of solution are used for each plate and the plates are developed in a 10¼ in. by 8-in. stainless-steel dish, supported on a wooden frame and kept in contact with a large volume of water at a temperature such as to maintain the developer at 20° C. Immediately after immersion the plate is lightly squeegeed with a flat rubber squeegee during about 7–8 sec., after which the dish is agitated till the end of the first 15 sec. of development; it is then allowed to stand without movement until development is complete. A brief immersion in an acetic acid stop bath follows, and the plate is then transferred to an acid hardening and fixing bath for 5 min., followed by 5–10 min. washing in frequent changes of running water.

[1] A two-solution developer containing equal parts of: (*a*) 25 g. of hydroquinone, 25 g. of potassium metabisulphite, 25 g. of potassium bromide in 1 litre. (*b*) 50 g. of potassium hydroxide in 1 litre.

[2] A single solution containing: 2·2 g. of metol, 144 g. of sodium sulphite cryst., 8·8 g. of hydroquinone, 130 g. sodium carbonate cryst., 4 g. of potassium bromide in 1 litre.

It is finally wiped with a viscose sponge and dried in a current of warm dust-free air from a diffusion-type hair dryer.

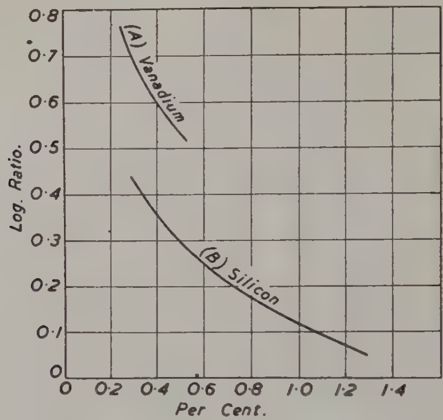

FIG. 8.—Curves for Steel *A*; *A* vanadium, *B* silicon.

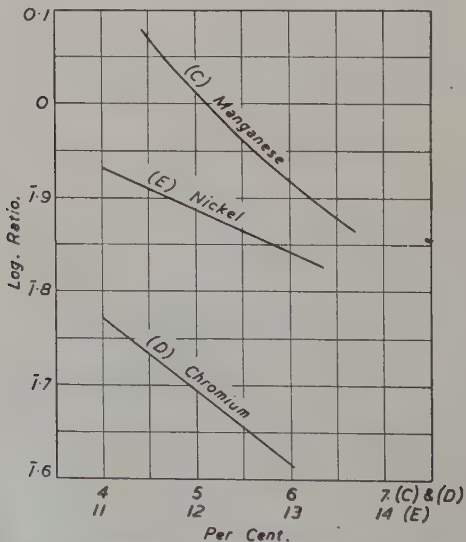

FIG. 9.—Curves for Steel *A*; *C* manganese, *D* chromium, *E* nickel.

The precautions necessary during the subsequent photometry, as well as the method of interpretation of the results, have already been sufficiently indicated in the preceding Section. Typical series of log.-ratio/concentration curves are given in Figs. 8 to 11.

The amount of deviation from the correct figures varies in spectrographic work with the amounts of the particular elements present and the sensitivity of the lines used. This latter is a very variable quantity, as shown by the figures given in Table VI.

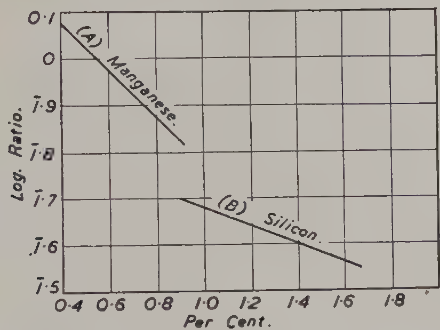

Fig. 10.—Curves for Steel *B*; *A* manganese, *B* silicon.

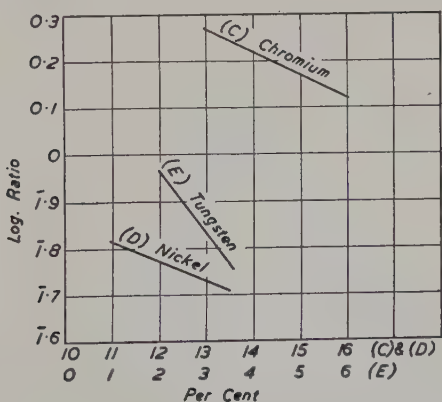

Fig. 11.—Curves for Steel *B*; *C* chromium, *D* nickel, *E* tungsten.

Table VI.—*Typical Equivalent Percentage Change in Composition for a Log.-Ratio Change of* 0·1.

Element.	Steel *A*.	Steel *B*.
Silicon	0·4	0·5
Manganese	1·1	0·2
Chromium	1·3	2·0
Nickel	2·2	2·4
Vanadium	0·1	...
Tungsten	...	0·75

It is clear from these figures that, while the errors in the estimation of vanadium are likely to be very small, the determination of nickel, for example, must be very carefully carried out if errors are to be kept within ¼% of this element.

The maximum routine spectrographic errors normally experienced in the case of the other elements are:

Silicon . . .	±0·1%.
Manganese . . .	±0·2% in steel *A* and ±0·03% in steel *B*.
Chromium . . .	±0·2% in steel *A* and ±0·3% in steel *B*.
Tungsten . . .	±0·15%.

The melting specifications involved are sufficiently wide to accommodate these errors without the need for an undue amount of checking. In practice values falling nearer to the specification limits then the errors indicated above are checked, and so long as the melting is not unnecessarily close to these limits few such checks are required.

Typical results for these two steels are given in Tables VII. and VIII., in each of which are detailed the results of twenty-five chemical checks on spectrographic figures obtained in the routine analysis of four hundred casts.

TABLE VII.—*Results of Twenty-Five Chemical Checks with Corresponding Spectrograph Figures covering* 400 *Routine Samples of Steel* A.

Cast No.	Silicon.		Manganese.		Chromium.		Nickel.		Vanadium.	
	Chemical.	Spectrographic.	Chemical.	Spectrographic.	Chemical.	Spectrographic.	Chemical.	Spectrographic.	Chemical.	Spectrographic.
1753	0·91	0·91	5·66	5·6	4·96	5·05	12·57	12·75	0·35	0·34
1770	0·85	0·89	5·69	5·8	4·98	4·85	12·45	12·65	0·35	0·36
1788	0·90	0·85	5·65	5·70	4·91	4·95	12·47	12·3	0·34	0·34
1802	0·92	0·87	5·76	5·6	4·95	4·85	12·59	12·7	0·34	0·33
1819	0·93	0·94	5·75	5·7	4·91	4·95	12·49	12·35	0·34	0·34
1835	0·87	0·97	5·66	5·75	4·93	5·05	12·46	12·7	0·33	0·34
1849	0·91	0·93	5·67	5·7	4·89	4·85	12·49	12·45	0·32	0·33
1867	0·90	0·94	5·67	5·7	4·94	5·1	12·56	12·3	0·32	0·33
1885	0·93	0·96	5·67	5·8	4·96	5·0	12·68	12·5	0·32	0·34
1903	0·91	0·91	5·72	5·75	4·92	5·0	12·57	12·5	0·33	0·33
1917	0·94	0·90	5·70	5·6	4·88	4·85	12·59	12·5	0·33	0·32
1933	1·06	1·08	5·82	5·85	4·91	5·0	12·55	12·4	0·32	0·35
1954	0·98	0·95	5·78	5·6	4·78	4·85	12·60	12·7	0·34	0·32
1971	1·03	1·01	6·12	5·85	4·59	4·8	12·67	12·6	0·34	0·33
1987	1·00	0·99	5·70	5·7	4·89	4·8	12·67	12·7	0·33	0·34
2007	0·90	0·89	5·65	5·55	4·91	4·8	12·62	12·5	0·33	0·33
2025	0·93	0·93	5·68	5·65	4·78	4·7	12·80	12·8	0·34	0·34
2047	0·93	0·91	5·65	5·65	4·88	4·85	12·71	12·75	0·34	0·33
2065	0·92	0·91	5·72	5·7	4·92	4·95	12·77	12·7	0·35	0·34
2081	0·95	0·94	5·40	5·55	4·90	4·90	12·40	12·25	0·34	0·33
2099	0·87	0·88	5·32	5·4	5·06	4·9	12·42	12·4	0·33	0·33
2119	0·90	0·85	5·39	5·35	4·81	4·6	12·49	12·45	0·33	0·32
2139	0·95	0·95	5·36	5·45	5·02	4·9	12·37	12·5	0·34	0·34
2157	0·88	0·90	5·32	5·5	5·16	4·95	12·34	12·3	0·35	0·34
2176	0·89	0·88	5·37	5·45	5·05	4·95	12·42	12·45	0·35	0·33

TABLE VIII.—*Results of Twenty-Five Checks with Corresponding Spectrographic Figures covering* 400 *Routine Samples of Steel* B.

Cast No.	Silicon.		Manganese.		Chromium.		Nickel.		Tungsten.	
	Chemical.	Spectrographic.	Chemical.	Spectrographic.	Chemical.	Spectrographic.	Chemical.	Spectrographic.	Chemical.	Spectrographic.
7101	1·36	1·33	0·57	0·55	14·65	14·55	12·28	12·3	2·72	2·92
7116	1·52	1·47	0·59	0·59	14·53	14·65	12·47	12·35	2·63	2·79
7131	1·47	1·36	0·57	0·55	14·67	14·65	12·55	12·5	2·70	2·75
7147	1·44	1·40	0·55	0·51	14·63	14·45	12·44	12·55	2·69	2·75
7163	1·48	1·38	0·58	0·57	14·45	14·55	12·51	12·25	2·59	2·67
7178	1·55	1·40	0·56	0·53	14·56	14·65	12·50	12·35	2·80	2·68
7194	1·40	1·42	0·61	0·64	14·68	14·5	12·62	12·65	2·65	2·76
7209	1·44	1·42	0·58	0·58	14·63	14·6	12·63	12·55	2·73	2·64
7225	1·54	1·48	0·58	0·54	14·53	14·55	12·65	12·75	2·65	2·68
7237	1·53	1·44	0·54	0·49	14·67	14·6	12·61	12·55	2·69	2·67
7252	1·59	1·56	0·54	0·52	14·62	14·8	12·48	12·55	2·60	2·70
7268	1·26	1·31	0·57	0·56	14·86	14·6	12·54	12·75	3·01	2·97
7282	1·19	1·18	0·54	0·51	14·84	14·7	12·49	12·55	2·81	2·94
7297	1·48	1·41	0·57	0·53	14·56	14·65	12·61	12·7	2·89	2·85
7312	1·29	1·37	0·62	0·60	14·44	14·75	12·71	12·6	2·69	2·85
7326	1·40	1·43	0·56	0·49	14·63	14·6	12·60	12·55	2·73	2·89
7341	1·48	1·50	0·57	0·58	14·52	14·55	12·55	12·75	2·67	2·76
7357	1·53	1·43	0·60	0·57	14·56	14·7	12·60	12·4	2·65	2·80
7373	1·46	1·50	0·54	0·52	14·52	14·75	12·62	12·45	2·63	2·75
7386	1·51	1·49	0·59	0·55	14·57	14·5	12·58	12·6	2·67	2·72
7402	1·34	1·50	0·60	0·59	14·70	14·65	12·56	12·5	2·63	2·87
7417	1·48	1·47	0·62	0·63	14·69	14·8	12·72	12·6	2·66	2·76
7434	1·40	1·43	0·56	0·55	14·81	14·7	12·75	12·6	2·69	2·77
7449	1·50	1·43	0·57	0·51	14·66	14·6	12·67	12·75	2·65	2·63
7466	1·46	1·46	0·56	0·54	14·62	14·7	12·68	12·7	2·66	2·75

PROCEDURE AND RESULTS FOR LOW-ALLOY STEELS.

After a considerable amount of experimental work with low-alloy steels the authors have eventually employed a technique

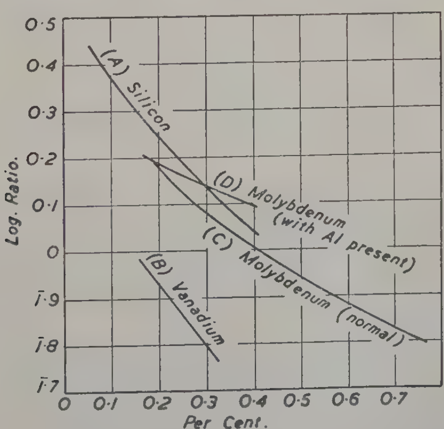

FIG. 12.—Curves for Low-Alloy Steels; *A* silicon, *B* vanadium, *C* molybdenum (normal). *D* molybdenum (with aluminium present).

essentially similar to that used for the high-alloy steels *A* and *B*.

The conditions for taking the spectra are the same as for these latter steels, except that the exposure consists of two superimposed 20-sec. periods, development being for 3–4 min. in *ID*13 developer. Correction for density is applied from the standard characteristic-curve figures in the normal way and five standard samples are normally used to determine any necessary slight adjustments of the composition curves.

The composition curves used are illustrated in Figs. 12 and 13; it is evident that, with the range covered, the application of a small

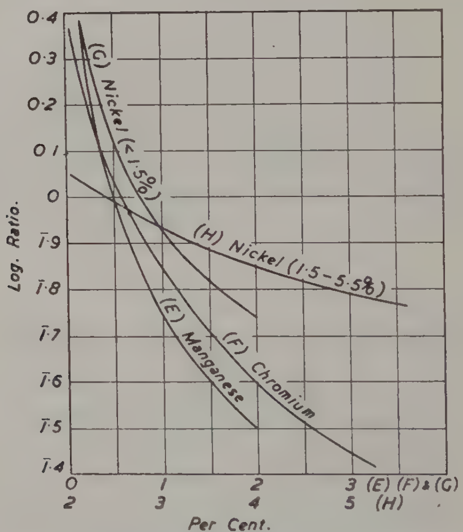

FIG. 13.—Curves for Low-Alloy Steels; *E* manganese, *F* chromium *G* nickel (<1·5%), *H* nickel (1·5–5·5%).

fixed correction to all the results for a given element on a single plate is no longer permissible. Instead, tracings of the various curves are set over fixed axes in such a position that, for the plate in question, they give the best average correspondence to the values obtained for the five standards. Values for the routine samples are then read off.

The line pairs used for this low-alloy steel work are detailed in Table IX. and illustrated in Fig. 5. Table X. gives the results of duplicate determinations on a series of fifty casts which were also put through normal routine chemical analysis. Spectra from each sample were taken on two spectrographs, the results being designated as *B* and *C*, respectively.

Table IX.—*Line Pairs Selected for the Analysis of Low-Alloy Steels.*

Element.	Range.	Element Line.	Iron Line.
Silicon	Up to 0·4%.	2881·58	2885·93
Manganese	Up to 2·0%.	2933·06	2936·90
Chromium	Up to 3·5%.	3408·76	3404·36
Nickel	Up to 1·5%. 1·5 to 5·5%.	3414·77 3515·05	3413·14 3513·82
Molybdenum	Up to 0·8%, except for steels with 1% aluminium.	2816·15	2813·61
	Up to 0·3% for steels with 1% aluminium.*	3170·35	3161·95
Vanadium	Up to 0·3%.	3102·30	3100·67

* Necessary because the aluminium interferes with the 2816·15 line.

It is not practical to specify overall limits of accuracy for the determination of the various elements when dealing with such a varied collection of steels, since these limits vary with the amount of the element present, but a good indication can be obtained for any particular range by inspecting the results. Some portion of the observed differences will, of course, be due to the normal inaccuracies of the chemical analyses, the figures given being taken from ordinary routine determinations, but in general the chemical errors can be taken as small.

As to how far the indicated accuracy will permit of practical application of the method can only be decided with a full knowledge of the circumstances operating in any particular case. Where it is possible to reduce considerably the composition range dealt with on individual plates, increased accuracy with fewer standards should become possible.

Other Developments.

In this account of the application of spectrography to steelworks analysis, the authors have been chiefly concerned with the routine analysis of low-alloy steels and of two high-alloy steels with which they have had extensive experience, but it is obvious that there must be many other directions in which the technique developed can be usefully employed. In fact, numerous applications have already been found in their work on both the routine and the research sides. For example, the same procedure has been successfully applied to the routine checking of small amounts of molybdenum and copper in low-alloy steels, many hundreds of casts having been dealt with in this way. The method also offers considerable scope in studying segregation, and has already proved valuable in this

TABLE X.—*Spectrographic Analysis of Low-Alloy Steels using*

Silicon.			Manganese.			Chromium.		
Chemical Figure.	Spectrographic Difference.		Chemical Figure.	Spectrographic Difference.		Chemical Figure.	Spectrographic Difference.	
	B.	*C.*		*B.*	*C.*		*B.*	*C.*
0·28	−0·02	−0·02	0·64	+0·03	+0·03	0·12	0·00	0·00
0·29	+0·02	+0·02	0·58	−0·01	0·00	1·66	+0·01	+0·02
0·26	+0·01	+0·01	0·55	0·00	−0·01	1·64	+0·03	−0·01
0·20	+0·01	+0·01	0·36	−0·01	−0·02	0·08	−0·01	+0·01
0·18	+0·03	+0·04	0·29	−0·02	−0·01	0·08	+0·04	+0·02
0·22	+0·03	+0·03	0·43	−0·01	+0·02	0·46	+0·04	+0·01
0·27	−0·02	+0·01	0·55	−0·03	−0·03	1·39	−0·06	−0·01
0·28	−0·02	0·00	0·59	−0·03	0·00	0·83	0·00	+0·04
0·21	+0·01	+0·01	0·24	−0·01	0·00	0·08	−0·02	+0·01
0·23	0·00	+0·02	0·69	−0·02	−0·02	0·17	+0·01	−0·02
0·34	−0·02	0·00	0·41	0·00	+0·03	3·15	−0·17	−0·04
0·30	−0·01	+0·01	0·37	−0·02	−0·02	1·53	−0·01	+0·04
0·31	−0·01	−0·01	0·53	−0·04	+0·01	1·70	−0·03	−0·02
0·23	+0·03	+0·03	0·57	−0·02	+0·01	0·10	+0·02	−0·03
0·27	0·00	+0·02	0·30	−0·02	−0·01	1·50	+0·03	+0·05
0·22	+0·03	+0·03	0·26	+0·02	+0·02	0·07	−0·03	+0·03
0·21	0·00	+0·01	0·28	−0·01	0·00	0·05	+0·03	−0·01
0·22	+0·03	+0·03	0·45	−0·03	−0·01	0·42	+0·02	+0·05
0·24	0·00	+0·04	0·19	0·00	−0·02	0·06	−0·01	+0·01
0·30	−0·01	+0·01	0·53	−0·01	0·00	1·62	+0·09	+0·08
0·26	−0·01	−0·03	0·64	−0·01	−0·02	0·88	0·00	+0·04
0·20	−0·01	0·00	0·26	−0·01	−0·02	0·08	0·00	+0·02
0·14	+0·01	0·00	0·28	+0·01	0·00	0·09	+0·01	0·00
0·19	−0·02	−0·01	0·31	−0·02	−0·02	Trace	...	...
0·22	0·00	0·00	0·39	+0·02	+0·01	0·06	+0·02	+0·02
0·20	0·00	−0·02	0·29	+0·01	+0·02	0·09	0·00	+0·02
0·18	+0·02	+0·02	0·37	0·00	+0·01	0·80	0·00	+0·07
0·25	−0·03	−0·02	0·74	0·00	−0·01	0·06	+0·01	+0·01
0·35	0·00	+0·01	0·53	−0·02	+0·02	1·75	+0·04	+0·10
0·24	−0·02	−0·01	1·23	+0·02	+0·06	Trace	...	...
0·22	0·00	0·00	0·45	−0·03	−0·02	3·08	0·00	−0·11
0·25	+0·01	0·00	0·13	+0·01	0·00	2·01	−0·03	+0·04
0·27	−0·01	+0·01	0·47	+0·01	−0·03	0·11	+0·02	0·00
0·31	−0·02	+0·03	0·55	+0·02	+0·01	1·67	+0·01	−0·04
0·22	−0·01	−0·01	0·68	+0·02	+0·02	0·09	−0·02	−0·02
0·21	+0·01	+0·02	0·64	+0·02	+0·03	0·10	+0·01	−0·02
0·25	+0·05	+0·03	0·14	+0·03	+0·01	2·23	−0·03	−0·04
0·28	−0·03	0·00	0·50	−0·01	+0·02	1·39	+0·01	−0·04
0·23	+0·05	+0·05	0·11	0·00	0·00	2·11	0·00	−0·04
0·36	−0·03	+0·01	0·39	−0·01	−0·03	1·65	−0·13	−0·02
0·20	+0·02	+0·03	0·46	−0·02	0·00	0·10	+0·04	−0·03
0·23	+0·02	+0·05	0·61	−0·01	−0·01	1·11	−0·08	−0·03
0·21	0·00	+0·02	0·55	−0·05	−0·01	0·11	+0·05	−0·02
0·19	+0·05	+0·04	0·11	+0·02	+0·02	2·03	0·00	0·00
0·28	−0·01	+0·03	0·60	−0·02	−0·01	0·98	+0·02	−0·06
0·21	+0·01	+0·01	0·92	0·00	+0·03	0·79	+0·01	−0·01
0·18	0·00	+0·01	0·92	0·00	0·00	0·78	+0·04	+0·04
0·18	+0·03	+0·02	0·94	+0·03	−0·03	0·78	+0·03	+0·03
0·28	−0·02	−0·01	1·83	−0·03	+0·05			
0·29	−0·01	−0·02	1·98	0·00	−0·04			

respect. On the research side the detection and estimation of small quantities of "impurity" elements or special additions often calls for arc rather than spark technique, but much useful information has been obtained by this means.

Much additional investigation has also been carried out in regard to the possible routine analysis of other medium- and high-alloy materials. Promising results have been obtained in many directions, and, although it has not yet proved possible to obtain the required degree of accuracy with alloying elements such as chromium and

Photo-Correction from Characteristic Plate Response Curve.

Nickel.			Molybdenum.			Vanadium.		
Chemical Figure.	Spectrographic Difference.		Chemical Figure.	Spectrographic Difference.		Chemical Figure.	Spectrographic Difference.	
	B.	*C.*		*B.*	*C.*		*B.*	*C.*
3·48	−0·13	+0·04						
0·07	+0·04	0·00	0·22	0·00	−0·01			
0·09	+0·04	−0·01	0·23	0·00	−0·01			
2·96	−0·11	+0·06						
4·92	−0·17	+0·10						
2·74	−0·02	−0·01						
0·10	−0·01	−0·03	0·72	+0·04	−0·01			
3·64	−0·13	+0·01						
4·93	−0·02	+0·08						
3·59	−0·03	+0·06						
0·25	+0·02	−0·01	0·49	−0·02	+0·01			
0·13	+0·05	0·00						
0·15	+0·03	0·00	0·22	+0·01	+0·01			
3·62	+0·03	+0·01						
0·13	+0·04	+0·01						
4·87	−0·12	−0·09						
4·88	−0·03	0·00						
2·72	+0·04	−0·06						
0·07	+0·08	+0·08						
0·16	+0·02	0·00	0·21	0·00	0·00			
0·13	+0·02	−0·03						
4·96	−0·16	−0·03						
0·28	0·00	−0·02						
4·92	−0·12	+0·10						
5·35	−0·08	+0·06	0·24	−0·02	−0·02			
5·37	−0·01	−0·05	0·25	0·00	−0·01			
3·34	−0·04	+0·09						
0·56	−0·09	−0·01						
0·25	+0·03	+0·01	0·21	−0·01	+0·01			
0·14	+0·02	−0·01						
0·21	−0·02	0·00	0·42	−0·03	0·00			
1·94	−0·05	0·00						
0·15	−0·01	−0·01						
0·09	+0·02	−0·01	0·21	0·00	−0·01			
2·55	+0·10	+0·05	...	...	...	0·17	−0·02	−0·02
3·28	+0·09	+0·06						
2·18	+0·07	+0·03						
0·13	+0·03	+0·03						
1·97	−0·04	+0·07						
3·52	+0·15	−0·15						
0·23	0·00	0·00						
3·29	−0·09	−0·03	0·59	+0·03	+0·05	0·26	−0·01	−0·02
0·14	+0·04	+0·01	0·62	+0·02	0·00			
1·97	+0·08	+0·01						
3·16	+0·03	+0·10	0·62	+0·02	+0·01	0·25	+0·01	0·00

tungsten when present in amounts as high as 18–20%, interesting results have been obtained even with such high percentages.

In conclusion, acknowledgment is made of the encouragement which the authors have received in this interesting study from Dr. W. H. Hatfield, F.R.S., Technical Director of Messrs. Thos. Firth and John Brown, Ltd., and Firth-Vickers Stainless Steels, Ltd., and to the directors of Messrs. Thos. Firth and John Brown, Ltd., and Firth Vickers Stainless Steels, Ltd., for permission to publish the results of the researches.

CORRESPONDENCE.

Dr. A. G. QUARRELL (Sheffield University) wrote : I am glad to see that the authors have put into practice a number of recommendations which Dr. Bramley and I made some two years ago,[1] and that successful results have been obtained.

I think that the authors would be wise to lay greater stress upon the fact that their use of the term " log. ratio " is different from that of most earlier workers. The log. ratios used by Barker, for example, will agree with those of the present authors only if the spectrum lines have been recorded with densities corresponding to the straight-line portion of the density/log.-exposure characteristic curve of the photographic plate. The present work confirms our conclusions (*loc. cit.*) that this straight-line portion of the density/log.-exposure curve is normally extremely limited when expressed in terms of photometer deflections, and that in only a small proportion of cases is the use of the *usual* log.-ratio method justified by theoretical considerations. In the technique developed by Barker, all conditions are standardised so rigorously that the correction to be applied by the log. ratio is small in all cases, and even when the spectrum lines fall in the region of under-exposure, so that the normal log.-ratio method is not strictly applicable, the resulting error is small. The present authors, on the other hand, have endeavoured to eliminate even these small sources of error by determining and making full use of the characteristic curve of the photographic plate.

On receipt of a new batch of plates, the authors determine the shape of the characteristic curve of the emulsion, using a high-pressure mercury-vapour lamp for the purpose. From the results reported in Figs. 6 and 7 it is concluded that the form of this characteristic curve is remarkably stable over a period of as much as sixteen months and from batch to batch, and is virtually independent of the conditions of development. In addition, the authors state that differences in development time, speed of the particular plate and the intensity of the light used all displace the characteristic curve horizontally. Since these conclusions and observations do not agree with those of other workers, it would be interesting to know to what extent the results upon which they are based are repeatable? Do Figs. 6 and 7 represent the results of isolated experiments, or have they been repeated several times? If these figures do not give a misleading picture of the position with regard to photographic technique, one is justified in assuming that the photographic side of spectrochemical analysis is on a completely sound basis. Yet the authors find it necessary to include on each plate a number of spectra of " standard " samples " to cover any day-to-day variations in the response of the material." These so-

[1] Quarrell and Bramley, *Journal of the Institute of Metals*, 1941, vol. 67, Part 1, p. 25.

called standards are usually taken from the previous day's chemical checks, and their use is therefore open to serious criticism. Such standard spectra ensure a closer link-up with the results of chemical analysis, and this would account for the close agreement observed between spectrographic and chemical results, but an equal number of suitable exposures with a more reliable and reproducible source such as the mercury-vapour lamp would afford a better method of allowing for day-to-day variations in the response of the material and would enable the characteristic curve to be directly checked for each plate.

It would have helped in the assessment of the authors' work if they had indicated the extent of the corrections applied in the analysis of both high- and low-alloy steels on the basis of the standard spectra.

Finally, it would have been useful if Tables V. and IX. had included additional columns giving the range of photometer deflections normally encountered for the various element and iron lines in the authors' practice. It may be that the choice of example to illustrate the method of calculating log. ratios at the top of p. 316 P was unfortunate, for it certainly gives the impression that the authors most frequently worked on the upper curved portion of the characteristic curve. In this region (photometer deflection 0–10 cm.) the sensitivity of the method is variable and much less than when the average photometer deflection is in the neighbourhood of 30 cm. When six or seven different elements of varying concentrations are being estimated simultaneously, the most favourable photometer deflections cannot, in general, be used for all, but it would be interesting to know the extent to which this ideal has been approached in the present work.

Mr. E. van Someren (Murex Welding Processes, Ltd., Waltham Cross, Herts.) wrote: The paper is a welcome contribution as evidence of the reliability of the spectrograph as a tool for the routine analysis of metal samples (p. 301 P). The second conclusion one would be tempted to draw is that plate calibration is too complicated a problem for the average analyst and that it is better to fall back on the re-photographing of standard samples on each plate, as the authors admit on p. 313 P. This actually makes most of the work described in pp. 303 P–312 P redundant. If log. ratios are plotted against log. composition the curvature such as is shown in Figs. 8 and 13 is usually eliminated and interpolation to get the results is facilitated. A few criticisms of details of the paper remain of interest.

It has been shown by workers both in the U.S.A. and in Germany that the errors of spectrochemical analysis (p. 302 P) follow a normal distribution law, and consequently the frequency of an error of any magnitude can be computed from the mean error, if the mean error is given in the form of a standard deviation and not of an average.

The term maximum error is ambiguous—does it mean the total amount present, or the biggest error which the analyst would make without becoming so suspicious as to repeat the test?

This links up with a point on p. 321 P, where the authors suggest that, in general, the chemical errors in a routine laboratory can be taken as small. One cannot contradict such a vague remark; but it is enough to point out that in order to compare the accuracy of two methods one must evaluate the errors of each by a quantitative statistical comparison. Examination of the analytical certificates issued with a " standard steel " will indicate the magnitude of the errors to be expected.

The stability of the maximum slope of the characteristic curve of ordinary plates developed in *ID*13 for between 2 and 5 min. at 20° C. (p. 309 P) is not remarkable, since this developer usually completes its work in $1\frac{1}{2}$ min. at that temperature. The increased density obtained, Table III., is most surprising, and I would like to hear the comments on this point of a photographic plate manufacturer.

As a speedy method of plate calibration (p. 311 P), we have found the step-wedge recently marketed by Messrs. Adam Hilger, Ltd., rapid and space-saving; seven exposures are recorded on 9 mm. of plate in one operation, with density differences corresponding to intensity ratios of 1·56 between consecutive steps.

Mr. D. M. Smith (British Non-Ferrous Metals Research Association, London) wrote : While this paper gives a good account of the development of the methods used by the authors, following on from the classic paper by Barker,[1] I feel that there are a number of points which call for criticism.

The magnitude and frequency of the errors encountered are certainly important, but these can be determined by the application of statistical methods. If the standard deviation be determined from the results obtained from 25 or more spectra of the same sample this quantity provides the information sought. Thus, suppose we derive a standard deviation of 4% (of the average content), then the deviation of one in three results will exceed 4%, one in 22 will exceed 8% and one in 370 will exceed 12%. There is ample evidence available now to show that with a satisfactory spectrographic method the errors encountered are random errors and are therefore amenable to statistical study.

With regard to methods for processing photographic plates, it was realised by the Spectrographic Research Sub-Committee of the British Non-Ferrous Metals Research Association that this was an important problem. Accordingly in December, 1941, a Panel was formed to consider photographic problems, to which representatives of the plate manufacturers were invited. It is on the findings of this Panel that I base my criticisms of the photographic technique

[1] *Journal of The Iron and Steel Institute*, 1939, No. I., p. 211 P.

used by the authors. Uniformity in development demands continuous removal of the products of development and this is only achieved by continuous agitation of the developer. I cannot agree with the statement that fixing, hardening and washing are not critical. It is possible that the method used by the authors is responsible for the somewhat pessimistic view that they find it useful to use only one-third of the length of the line in the photographed spectrum.

The use of the mercury lines 3654·83 Å. and 3666·28 Å. for calibration purposes is unsafe for the determination of silicon by the line pair Si-2881·58/Fe-2875·34, as the contrast factor for these two wave-length regions is quite different for the types of emulsion used in spectrographic work.

Dr. J. Convey (The Admiralty Laboratory, The University, Sheffield) wrote: This paper indicates that a considerable amount of hard experimental work has been done by the authors. Unfortunately, I found that to understand many of their explanations I had to reread the paper several times and then reinterpret their remarks. The title is misleading, as only one method of analysis is critically considered.

The main contribution of the paper is that of the spectrochemical analysis of two high-alloy steels with the aid of a technique called "photo-correction," obtained from characteristic plate-response curves. The accuracy of the quoted results is excellent, but is this accuracy due to the novel photo-correction or to the many standard samples exposed on each plate? Have the authors compared results produced by their technique with those obtained from the usual log.-ratio/concentration calibration, when appropriate standard steels are exposed on each plate?

The authors claim that Table I. explains in detail that the influence of variation in spark-gap width has two effects on the results, which are adequately compensated for by means of a photo-correction. The first effect is a modification of the overall intensity of the spark. This effect is assimilated by keeping the spark gap constant and varying the exposure time. The results as quoted in the first half of Table I. show that the photo-correction technique is as good as, but no better than, that of the easier log.-ratio/concentration technique.

The second half of Table I. illustrates the fact that in addition to the overall intensity change there may be appreciable inherent intensity changes of various spectral lines as the gap width is modified—a variability which the photo-correction does not remove. Have the authors studied the spectral classification of the line pairs that they employed? One has to assume that the spectral line pairs used to obtain the results in Table I. are those quoted in Table V. If the authors had adopted their own recommendation on the selection of homologous spectral line pairs, as quoted on p. 305 P,

then they could have explained the inability of the photo-correction to correct for the variations shown in Table I.

Consider, for example, the results on nickel; it is obvious that whatever happened in the disc experiment was also inherent in the gap-modification experiment. The photo-correction and log.-ratio techniques agree. This significant fact shows that the problem is entirely one of ionisation, which renders the authors' interpretation of the results very doubtful A study of the spectral line pairs given in Table V. shows that only the Ni-3510/Fe-3497·84 Å. pair is homologous. They are both arc lines. The silicon, manganese, chromium, vanadium and their respective iron spectral lines are not homologous pairs but are respectively combinations of arc and spark lines. The results quoted in Table VI. add further evidence to the above. Therefore, can the authors justify their claim concerning Table I. that the photo-correction technique is superior to the log.-ratio/concentration technique? Both methods employ the log.-ratio standardisation, only the photo-correction adds further work in its practice. The results quoted in Table I. are good and are worthy of better treatment than the authors have given them.

On p. 306 P the first sentence, "Local irregularities in the emulsion, &c.," is worth noting, as the method of processing the photographic plates mentioned on p. 307 P would help in the evolution of such defects. The processing technique quoted in this paper implies everything that one is not supposed to do. What variations in procedure of plate processing have the authors tried and how did their results compare with those of the method adopted by the authors? Perhaps the reason why the authors (p. 306 P, bottom) find it very useful to employ only about a third of the $1\frac{1}{2}$-mm. length of spectral line is provided by their processing technique. Can the authors give a comparison of the relative freedom of the various types of plates that they have tried from the defects quoted on p. 306 P? Have they compared these results with those of similar plates processed according to the more common technique where a squeegee and sponge are not used and gentle rocking is carried on during development? That is, how does the authors' work compare with that of Vincent and Sawyer? [1] What are the advantages of the two-solution developer used by the authors over the commonly accepted one-solution developer?

Why do the authors make such a statement as that on p. 307 P, fifth line from the bottom, namely, " A decrease in speed, &c. . . ." and then contradict it with the results illustrated in Fig. 7 and the sentence on p. 312 P, fourth line, "In view of this constancy of form, &c. . . ."?

Table II. shows the " influence of length of sparking time on log. ratios for steel *A*," but the authors have also included an " apparent-content " result for each respective element as obtained from calibration curves using 12-sec. exposures. Do the authors

[1] *Spectrochemica Acta*, 1939, vol. 1, Oct., pp. 131–136.

consider this a legitimate practice? Would it not be advisable to omit the apparent-content column from Table II.? However, the authors adjust the effect of minor variations in exposure by a variation of the development time, Fig. 6; Table III. is used to illustrate this claim. How do the authors assimilate this work with that of other authors who have found that a change in development time introduces two grave errors into concentration calibration curves as obtained by characteristic-curve analysis, namely, (*a*) retardation of development effect, and (*b*) failure of the reciprocity law?

Can the authors give a measure of the relative contributions to the empirical corrections shown in Table III. of (1) a difference in development time, (2) the speed of the particular plate used and (3) the intensity of the light?

It is interesting to note that both Figs. 6 and 7 illustrate the characteristic curves of two different plates and both show photometer readings plotted against log t. In Table IV. values of photometer readings are quoted against log I readings. Do the authors assume that $\log I = \log t$? If not, then from what curves do the log I values come?

The calibration curves in Figs. 8 to 13 are good, but why did not the authors include a few experimental points in order to inform the reader how many standards were used in their derivation?

At the top of p. 317 P, the authors claim "the sensitivity of the lines used is a very variable quantity," in spite of the fact that most of the quoted calibration curves show a linear relationship between the log. ratio of intensity and the percentage content of element. Table VI. is supposed to indicate this variability, but on examination the reader learns that for the two alloy steels A and B the only common spectral line pair used is Ni-3510/Fe-3497, hence the agreement shown in the fourth line of Table VI. The small difference between 0·4 for steel A and 0·5 for steel B in the first line is due to the fact that, although the same silicon spectral line 2881·58 is used for both steels, two different iron lines are used, namely, Fe 2875·34 for A and Fe 2885·93 for B. The other line pairs are dissimilar. Do the authors wish to express by Table VI. that different spectral lines have different sensitivities? This is a sound conclusion, but how can they conclude that the sensitivity of the spectral lines used is a variable quantity? This problem is essentially one of plate response.

The accuracy of the results quoted in Tables VII., VIII. and X. is very good, and the reason is given on p. 313 P in the paragraph on the use of standard samples. The last sentence of this paragraph is equivalent to saying that each plate is calibrated by means of the standards, when the authors admit a relative freedom of motion of the calibration curves. As the authors have successfully analysed thousands of casts might I suggest that a careful statistical survey of the results would be very beneficial to the study of spectrochemistry.

AUTHORS' REPLY.

The AUTHORS wrote in reply : We have followed the work of Dr. Quarrell and Dr. Bramley on the spectrographic analysis of aluminium alloys with considerable interest and agree with many of the conclusions reached in the paper mentioned by Dr. Quarrell, although we do not find the suggested modification in working, based on the difference between the photometer readings, to be as satisfactory for steel analysis as the more usual log.-ratio method. We do not, of course, wish to claim originality in regard to the basic idea of correcting photometer readings according to the plate characteristics, such procedure having been recognised and applied by various workers in recent years. We believe, however, that the particular method of application described in the paper is new.

In the course of our work, we have prepared large numbers of curves dealing with plate characteristics, covering various types of plates over a period of years. We would make it quite clear that we did not set out with any preconceived idea as to the stability of form of the type of characteristic curve used; in fact, quite the contrary. In the early stages of the work we carried out mercury-vapour lamp calibrations on a series of plates and explored the possibility of using the relative density of selected iron lines as a method of individual plate calibration, but the steadiness of form of the mercury-line response curves made it evident that it would not be necessary in routine work to carry out individual standardisations of all plates. This was a valuable simplification of technique and made possible the tabulation of the calibration response as described in the paper and illustrated in Table IV.

We do not, of course, assume that no variations occur. Some recent deliveries of plates have shown such modification in response that new conversion tables have had to be prepared to deal with them. Nevertheless, it remains true that, within a given batch, and often from batch to batch, tables based on a single curve provide effective density correction. Final adjustment is made by checking the behaviour of the "standard" samples on each plate. These standards, as explained in the paper, also serve to check any batch variation in response of the steel analysed. With the higher-alloy materials we have found that such variations do occur, and lead to a somewhat decreased accuracy unless checked by the use of recent samples of known analysis in addition to any older, established standards which may be employed.

Dr. Quarrell will find an indication of the range of photometer deflection encountered with steel *A*, on Kodak *B*20 plates, from the normal readings given in Table A, prepared in connection with the reply to Dr. Convey.

Mr. van Someren argues from the continued use of standards that the plate-calibration work is redundant. This is certainly not the case. Table A illustrates the serious divergence which can

result from individual fluctuation in spectral density, and, while the density changes illustrated there may be larger than would normally occur in practice, some variation is to be expected and must entail loss of accuracy unless corrected. Moreover, such correction minimises changes in slope and shape of the composition curves, which can otherwise occur as a result of overall differences in density between plate and plate. This is a valuable point, even with the use of standards, when the highest accuracy is required, and particularly when large composition ranges must be covered on a single plate with relatively few standards.

We have certainly not ignored the possibilities of statistical study of the spectrographic technique. We have, for example, read with much interest the recent account of the application of such methods by H. B. Vincent and R. A. Sawyer,[1] in which, working under carefully controlled conditions and with a single standard material, these workers have obtained information as to the magnitude of various sources of error in their equipment and procedure. This is a different matter from attempting to obtain useful statistical data from routine results with only a limited number of check chemical analyses, or even from special plates where all the analyses have been checked, but where the seventeen samples involved may, in the case of the low-alloy materials, for example, cover a wide range of composition, and where any one of the samples may have some special idiosyncrasy of response. Even assuming that statistical treatment can be usefully applied in such cases, we still stress the point that it is the frequency of occurrence of errors of considerably higher magnitude than the calculated standard error which determines most effectively the useful limits of practical application of the method.

The expression "maximum errors" was used in the paper to indicate the largest errors in the analytical figures which would occur in practice when dealing with large numbers of routine determinations. Such errors can occur without necessarily arousing any suspicion in the mind of the analyst, since their effect can be to make an unsatisfactory cast appear to be satisfactorily within specification. When the error is such as to indicate failure to meet the specification in a good cast, it is, of course, more likely to be questioned and the determinations checked.

We do not feel that statistical treatment of the chemical errors of the order of $\pm 0{\cdot}02\%$ maximum on, say, a $0{\cdot}5\%$ manganese content would be of much practical value. Even with the 12% of nickel present in steels *A* and *B*, in our experience the chemical analysis is regularly carried out within a tolerance of $\pm 0{\cdot}1\%$ of nickel.

We have found no advantage from the use of log.-composition/

[1] Tenth Summer Conference on Spectroscopy and Its Applications, *Journal of the Optical Society of America*, 1942, vol. 32, No. 11, Nov., pp. 686–692.

log.-ratio curves in place of the normal composition/log.-ratio curves.

Under our conditions, with only preliminary agitation of the developer, development in *ID*13 solution is certainly not complete in $1\frac{1}{2}$ min. The results of the deliberations of the Panel on photographic materials and processing referred to by Mr. Smith will be awaited with much interest by all workers in this field. For the present, we still prefer the method of development which we have described, although we have recently encountered some very thin emulsions which even the lightest treatment with a squeegee tended to mark and which could not satisfactorily be dried in the usual current of warm air. This has led to the use of a wetting agent to promote uniform initial wetting of the emulsion by the developer, in place of the very light stroking with a flat rubber squeegee

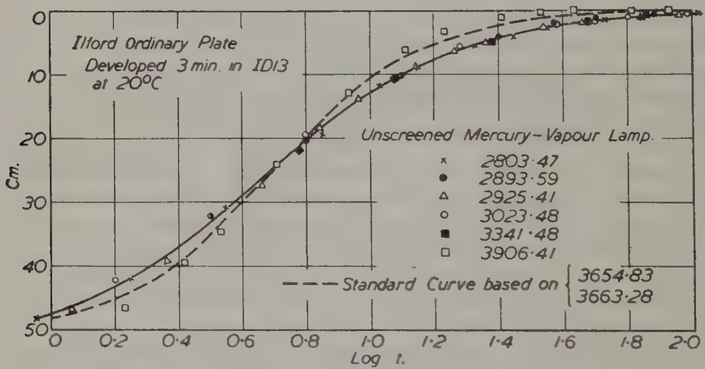

FIG. A.—Effect of Wave-Length on Plate Characteristic Curve.

previously employed, with very satisfactory results. Only one batch of plates was affected by the drying trouble, and in this case the emulsion was so thin that drying at ordinary temperatures was quite rapid and satisfactory. Such points require constant watchfulness on the part of the operator, but we suggest that a careful study of unprocessed plates and of uniformly fogged and processed plates will reveal to Mr. Smith and Dr. Convey other reasons than our methods of processing which make it useful in practice to employ only a portion of each line for the normal reading.

We were aware of the fact mentioned by Mr. Smith that the response of the plates would be somewhat different at different wave-lengths, although results such as those given in Table I., as well as experience in actual determinations, have indicated the generally satisfactory nature of the 3655–3663 Å. curve. We

examined the quantitative aspect of this effect by drawing calibration curves for a series of mercury lines from 2803·47 Å. to 3906·41 Å. In Fig. A are plotted the results from such series taken from an Ilford Ordinary plate developed in *ID*13 developer. Similar results were obtained with a Kodak *B*20 plate developed in *D*19*b* developer. For the purpose of comparison, the values obtained for the various lines have been superimposed by the application of a suitable factor as described in the paper, the adjustment being made in this case to establish coincidence of the various series in the 20–25 cm. region. It will be seen that the points based on lines of wave-lengths from 2803·47 Å. to 3341·48 Å. fall sensibly on a single curve, which has a somewhat lower slope than the normal, higher wave-length curve. On the other hand, the difference in shape over the limited portion of the curves corresponding to ordinarily experienced fluctuations in density for a given line is not great, and series of results worked out by the two curves failed to show any justification for complicating the technique by the use of more than the one curve. It is, of course, conceivable that in some circumstances the matter might be of real practical importance.

We note Dr. Convey's remarks concerning the title of the paper, but in this connection we feel that he has misunderstood its essential objects. These were, first, to consider critically, in the light of our extensive practical experience, the degree to which this method can usefully be employed as a substitute for normal routine chemical analysis under steelworks conditions such as those described in the paper, and, secondly, to indicate the precautions and modifications of technique which we had found it necessary to introduce to reduce existing sources of error sufficiently to make possible our routine work on steels *A* and *B*. It was intended that the paper should in this way serve as a useful source of information to those considering the possible applications of the method in steelworks practice. Thus, although mathematical or theoretical considerations could have been developed at much greater length, it was considered that this would have unduly lengthened and complicated the account for the purpose in view.

With regard to Dr. Convey's remarks on photo-correction, we found very early in our work that some form of such correction was desirable, and it has consequently been included in the whole of our routine work. Originally it was applied empirically (p. 311 P) and later by means of the characteristic curves. This latter procedure has proved more convenient as well as more accurate. The degree of increased accuracy obtained varies with the density of the lines involved and also with the difference between the density of the element line and the comparison iron line. Perhaps the best way of illustrating the magnitude of the corrective effect introduced is by a comparison such as that provided in Table A. In this Table, in the two columns dealing with normal spectra are given actual results obtained with a sample of steel *A* on a Kodak *B*20

TABLE A.—*Influence of Photo-Correction with Steel A and Kodak B20 Plate.*

Element.	Chemical Analysis.	Dark Spectra. Calculated Photometer Readings.*	Dark Spectra. Uncorrected Log. Ratio.	Dark Spectra. Corresponding Photo-Curve Readings.	Dark Spectra. Corrected Log. Ratio.	Normal Spectra. Actual Photometer Readings.	Normal Spectra. Uncorrected Log. Ratio.	Normal Spectra. Corresponding Photo-Curve Readings.	Normal Spectra. Corrected Log. Ratio.	Light Spectra. Calculated Photometer Readings.*	Light Spectra. Uncorrected Log. Ratio.	Light Spectra. Corresponding Photo-Curve Readings.	Light Spectra. Corrected Log. Ratio.
		Fe. Si. 13·0 22·5 12·0 22·5	0·238 0·272 Mean 0·255	Fe. Si. 0·980 0·810 1·000 0·810	0·170 0·190 Mean 0·180	Fe. Si. 17·25 26·8 16·5 26·75	0·191 0·210 Mean 0·200	Fe. Si. 0·900 0·730 0·920 0·730	0·170 0·190 Mean 0·180	Fe. Si. 23·1 32·6 21·9 32·6	0·149 0·173 Mean 0·161	Fe. Si. 0·800 0·630 0·820 0·630	0·170 0·190 Mean 0·180
Silicon	0·77%	0·55%		0·75%		0·73%		0·75%		0·86%		0·75%	
		Fe. Mn. 15·8 10·3 15·8 10·3	$\bar{1}$·814 $\bar{1}$·814 Mean $\bar{1}$·814	Fe. Mn. 0·930 1·040 0·930 1·040	$\bar{1}$·890 $\bar{1}$·890 Mean $\bar{1}$·890	Fe. Mn. 20·35 14·25 20·0 14·2	$\bar{1}$·846 $\bar{1}$·851 Mean $\bar{1}$·848	Fe. Mn. 0·850 0·960 0·850 0·960	$\bar{1}$·890 $\bar{1}$·890 Mean $\bar{1}$·890	Fe. Mn. 25·9 19·7 25·9 19·7	$\bar{1}$·881 $\bar{1}$·881 Mean $\bar{1}$·881	Fe. Mn. 0·750 0·860 0·750 0·860	$\bar{1}$·890 $\bar{1}$·890 Mean $\bar{1}$·890
Manganese	5·74%	6·05%		5·85%		5·8%		5·85%		5·55%		5·85%	
		Fe. Cr. 17·5 6·2 15·8 5·9	$\bar{1}$·550 $\bar{1}$·572 Mean $\bar{1}$·561	Fe. Cr. 0·900 1·180 0·930 1·190	$\bar{1}$·720 $\bar{1}$·740 Mean $\bar{1}$·730	Fe. Cr. 22·0 8·25 20·4 8·15	$\bar{1}$·573 $\bar{1}$·602 Mean $\bar{1}$·585	Fe. Cr. 0·820 1·100 0·850 1·110	$\bar{1}$·720 $\bar{1}$·740 Mean $\bar{1}$·730	Fe. Cr. 27·6 12·0 25·9 11·6	$\bar{1}$·638 $\bar{1}$·651 Mean $\bar{1}$·645	Fe. Cr. 0·720 1·000 0·750 1·010	$\bar{1}$·720 $\bar{1}$·740 Mean $\bar{1}$·730
Chromium	5·10%	5·25%		5·0%		5·1%		5·0%		4·7%		5·0%	
		Fe. Ni. 19·1 18·6 17·5 16·3	$\bar{1}$·988 $\bar{1}$·969 Mean $\bar{1}$·978	Fe. Ni. 0·870 0·880 0·900 0·920	$\bar{1}$·990 $\bar{1}$·980 Mean $\bar{1}$·985	Fe. Ni. 23·7 23·0 21·8 20·6	$\bar{1}$·987 $\bar{1}$·975 Mean $\bar{1}$·981	Fe. Ni. 0·790 0·800 0·820 0·840	$\bar{1}$·990 $\bar{1}$·980 Mean $\bar{1}$·985	Fe. Ni. 29·3 28·8 27·6 26·5	$\bar{1}$·993 $\bar{1}$·982 Mean $\bar{1}$·987	Fe. Ni. 0·690 0·700 0·720 0·740	$\bar{1}$·990 $\bar{1}$·980 Mean $\bar{1}$·985
Nickel	12·15%	12·3%		12·2%		12·25%		12·2%		12·15%		12·2%	
		Fe. V. 24·25 9·0 23·0 9·0	$\bar{1}$·569 $\bar{1}$·593 Mean $\bar{1}$·581	Fe. V. 0·780 1·080 0·800 1·080	$\bar{1}$·700 $\bar{1}$·720 Mean $\bar{1}$·710	Fe. V. 28·5 11·7 27·55 11·8	$\bar{1}$·613 $\bar{1}$·632 Mean $\bar{1}$·622	Fe. V. 0·700 1·000 0·720 1·000	$\bar{1}$·700 $\bar{1}$·720 Mean $\bar{1}$·710	Fe. V. 34·5 17·5 33·2 17·5	$\bar{1}$·705 $\bar{1}$·722 Mean $\bar{1}$·713	Fe. V. 0·600 0·900 0·620 0·900	$\bar{1}$·700 $\bar{1}$·720 Mean $\bar{1}$·710
Vanadium	0·31%	0·35%		0·31%		0·32%		0·31%		0·27%		0·31%	

* The "dark spectra" readings have been calculated to correspond to illumination 20% above normal and the "light spectra" to 20% below.

plate,[1] worked out in one case on uncorrected log. ratios and in the second case by photo-corrected values. Other columns contain figures prepared by assuming a simple change in density of the two spectra concerned, corresponding to 20% greater intensity of illumination in one case and a 20% decrease in the other, the characteristic curve for the plate being used to deduce the new photometer readings. Thus the corrected log. ratios remain constant, as they should do with a simple overall change in intensity, but, owing to the non-linear plate response, the uncorrected log. ratios are appreciably modified by the assumed change in density. The corresponding effects upon the estimated element contents are shown in the Table.

Dr. Convey would appear to have misunderstood Table I. The object of this Table was not to show that variation of spark-gap width has two effects on the results which are adequately compensated for by means of a photo-correction, but, on the contrary, to show that, while the purely photographic part of the effect would be satisfactorily corrected by the use of the characteristic curve in the manner described, there remained over and above this a variation, no doubt related to ionisation effects, which was least sensitive to gap variation in the region of a $2\frac{1}{2}$-mm. gap width.

Naturally we would have preferred to adopt homologous line pairs in all our work, but, as explained on p. 305 P of the paper, this is very often an unattainable ideal in practical spectrography. Thus, if Dr. Convey will examine the low-alloy lines given in Mr. Barker's paper (*loc. cit.*) he will find that these are in most cases the same as the lines which we have used for this class of steel, and show similar differences in type. It is even at times necessary to admit the complication of incomplete resolution of interfering lines where no better alternative can be found, as discussed on p. 306 P. While we would not claim that no more satisfactory line pairs could be found in certain cases, those given are the most satisfactory which careful search has revealed in the region 2700–4300 Å. This region is the most useful for our work, since it includes both the silicon line 2881·58 Å. and the tungsten line 4008·75 Å., for which we have found no suitable alternatives.

We quite fail to understand Dr. Convey's statement that Table I. shows photo-correction technique to be as good as, but no better than, the easier log.-ratio/concentration technique. What Table I. does show in this connection is that photo-correction satisfactorily corrects the widely divergent log. ratios which would otherwise be

[1] As a matter of interest the results employed have been taken from a current series using 99·98% purity silver electrodes in place of the graphite electrodes described in the paper. This modifies the recorded log. ratios somewhat, but does not, of course, affect the correction principle. These electrodes have given results of similar accuracy to graphite electrodes, which they resemble in size and shape, and have the advantage of much greater durability, both generally and in respect of the much longer life of the pointed ends before resharpening becomes necessary. The exposure used is 10 sec. in place of the 12 sec. with graphite electrodes.

obtained with fluctuating density of spectra as a result of the purely photographic effect. The extent of the divergence is shown in the Table as the total correction required to bring the log. ratios into line with the half-disc or 2-mm. gap results, these being arbitrarily chosen as standards for the Table. The figures given in Table A illustrate what lack of such correction can mean under practical conditions of working. Dr. Convey can get some idea of the magnitude of the errors indicated by the fluctuations shown in Table I. by a comparison of the correction figures with the composition figures corresponding to a 0·1 change in the log. ratio for steel *A* (Table VI.).

As explained on p. 307 P, we have carried out numerous experiments on methods of development, particularly with uniformly fogged plates; in fact, this was one of the earliest studies in our spectrographic work, and has continued throughout. We have tried many variations of rocking technique and also various stroking and camel-hair-brushing treatments, but for standard routine work we found the method described in the paper the most satisfactory. Other points of processing technique have already been dealt with in reply to Mr. Smith.

Change in speed of plate, time and temperature of development or intensity of the illumination used can all modify the position of the working portion of the characteristic curve used with respect to the log t axis. This does not necessarily imply an appreciable change in form of the portion of the curve considered, and for the purposes of comparison the results for one plate have, where stated, been superimposed on the curve for another by a general movement with respect to the log t axis, equivalent, of course, to multiplying t by a constant factor. For the present work the interest lies in the difference between two readings, so that the absolute position in relation to the log t axis is immaterial. In this connection we cannot say precisely what proportions of the correction factors applied to the results in Table III. to produce Fig. 6 are related to development, speed of plate and intensity of the light, nor is this a matter of any consequence for the purpose for which the results were plotted.

Table IV. is part of a working table, in which we agree that it would have been more strictly correct to have retained the term "log t" or rather "log Kt" at the head of the log I column. It has been shown, however, that for the present work the log t curve can be satisfactorily employed for deriving corrected log. intensity ratios.

With regard to Table II., the "apparent content" columns were inserted simply to give a clearer appreciation of the degree of movement of the composition curves resulting from the changed exposures. As such we see no reason why the practice should not be considered legitimate.

The reason for not including a few experimental points in the calibration curves in Figs. 8 to 13 is that they were not derived from

a few points but from the extensive study of the response of some hundreds of production samples of known chemical analysis. This work has been carried out on an industrial scale on material which was already passing through in quantity with full chemical analysis before the spectrographic work commenced, so that, although a dozen or two samples covering a range of composition were selected in the first instance to obtain a general indication of the form of curves, their reliability was checked by a lengthy period of parallel working between spectrographic and chemical procedures before ultimately fixing final forms and positions. This does not, of course, mean that they could now be bodily transferred to another laboratory and immediately used as reliable under new conditions. They are given in the paper as a guide, but, as in all this work, each operator must standardise and fully check his own procedure under his own conditions, using the actual materials for which the work is required.

Finally, as regards the variability in sensitivity of the lines used (Table VI.), the point which we wished to bring out was that, at the various concentration levels concerned, and under the compromise conditions of exposure involved in dealing with five elements in a single spectrum, the most satisfactory lines found showed widely different sensitivities in terms of the actual concentration change for a given change of log. ratio. In this respect, for example, 0·1% of vanadium in steel *A* is equivalent to 2·2% of nickel in the same steel.

FIRST REPORT OF THE MARINE CORROSION SUB-COMMITTEE

OF THE CORROSION COMMITTEE.[1]

(Figs. 13 to 22 = Plates X. to XVII.)

Paper No. 9/1943 *of the Corrosion Committee* (*submitted by the Marine Corrosion Sub-Committee*).

CONTENTS.

SUMMARY.

Section A.—Introduction

The constitution of the Sub-Committee is stated and the scope of their investigations is discussed. The ultimate purpose of the Sub-Committee's work is to establish the most efficient and economic cures for both corrosion and fouling. The immediate scope of their activities includes an intensive study of the forms, rates and mechanisms of fouling, together with extensive investigations directed towards the establishment of improved formulations both for anti-corrosive and for anti-fouling ships' bottom compositions.

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[1] A Joint Committee of The Iron and Steel Institute and The British Iron and Steel Federation, reporting to The Iron and Steel Industrial Research Council.

Section B.—Raft Tests

Details of the experimental procedure adopted in the conduct of the Sub-Committee's raft tests are given and followed by a general description of the first two series of tests, which were made at Plymouth and Caernarvon on samples of proprietary painting schemes supplied by twenty-three different manufacturers. Some general observations are made concerning the formulation, media, pigments and toxins of these paints. Marked differences in consistency were observed from one sample to another, and the desirability of establishing a more uniform standard in this respect is stressed.

The performance of these commercial painting systems varied considerably; under raft-test conditions, when the rate of attack is accentuated as compared with service, the worst of them broke down within a few weeks when applied to new or even to repainted steel; the durability of the best exceeded one year.

An analysis of the development of fouling during the Caernarvon test showed that all types of fouling—slime, weed, hydroid and shell—were observed, that there was a seasonal effect in this development and that this was also affected by the distribution of light and by subsidiary incidental effects due to tidal movement.

Comparison of the Plymouth and Caernarvon tests showed that the results were reasonably reproducible. The main "ranked" painting schemes at Plymouth were also ranked at Caernarvon. As expected, there was a general improvement in performance when the painting schemes were applied over old paint, as compared with freshly pickled steel. At Caernarvon, the average lives to failure in these two cases were 16·2 and 10·7 weeks, respectively. Moreover, whereas the majority of failures on repainted surfaces were due to fouling, corrosion was the primary cause of failure on repickled ones. This emphasises that comparisons of anti-fouling compositions as such should be made only over satisfactory protective coats.

The life to failure by fouling as determined at Caernarvon on repainted specimens varied from a minimum of 5 to a maximum exceeding 56 weeks for the different proprietary compositions. There was a general but by no means exact correlation between these lives and the corresponding toxic indexes. (As described in Section C, the toxic index is the weighted aggregate percentage of copper, mercury and arsenic in the anti-fouling composition, the mercury content being multiplied by 2; arsenic (as As_2O_3) is almost ineffective, but in these tests a weighting factor of $\frac{1}{3}$ has been assumed.) It is considered that several of the most marked deviations from this correlation are due to the presence of organic toxins in the composition. The test shows that, on the average, in order to ensure a life of 6 months under the experimental conditions at Caernarvon a toxic index of at least 30 would be needed. This would correspond to the presence in the anti-fouling composition of 15% of mercury as mercury compounds, or 30% of copper as copper compounds, or of an equivalent mixture, with the reservation that it is doubtful whether mercury can completely replace copper.

With two painting schemes, the drying time allowed between putting on the anti-fouling composition and immersion was varied from $\frac{3}{4}$ to $19\frac{1}{2}$ hr., as compared with the standard interval of 5 hr. for the main test. These differences were not observed to have any systematic effect on the results obtained.

The variation in the protective properties of the painting schemes was as marked as that in the anti-fouling properties. The best were but slightly affected even after a year's immersion, whereas the worst suffered severe corrosion in only a few weeks. This variation is illustrated by results for the adhesion of the paints after test and the loss in weight of the various specimens on exposure. In terms of

steel the latter varied from nil to 1·48 oz. per sq. ft. at Plymouth and from 0·02 to 1·49 oz. per sq. ft. at Caernarvon; the durations of exposure were 29 and 26 weeks, respectively. Comparable losses for bare pickled steel exposed simultaneously were 1·78 and 1·39 oz. per sq. ft., from which it is obvious that the worst compositions were practically useless. In general the correlation of the Plymouth and Caernarvon results for the painting schemes common to both series of tests was good, *i.e.*, the orders of merit in regard to protective properties were substantially the same.

Another property investigated was the tendency for the painting schemes to promote pitting or local attack at "holidays," *i.e.*, gaps in the coating when the steel was left bare. This was done by leaving small areas, ½ in. square, unpainted when applying the coatings. It was found that the depth of pitting at these holidays after 6 months' exposure ranged from 0·007 to 0·080 in. Moreover, the results were substantially the same in both test series, from which it is concluded that the degree to which pitting is promoted at bare areas in a paint film is a characteristic property of the painting scheme used. At Caernarvon the worst pitting was associated with a scheme in which two coats of red-lead/oil paint were used as the protective immediately beneath the anti-fouling composition. This does not necessarily mean that red lead primers should not be used on ships' hulls, but it does point to the desirability that they should be suitably formulated for this purpose.

In general it is concluded from these two series of experiments that, although service tests must remain the final criterion of performance, particularly where anti-fouling properties are concerned, raft tests should give a good indication of the relative merits of protective compositions, and the results of these initial series should bear a substantial relationship to the probable behaviour in the case of painting schemes applied to new construction. New series of tests will include a study of the influence of the build-up of the coating resulting from successive repaintings.

Subsequent series of tests have been conducted on more fundamental lines. Series IV., begun at Caernarvon in January, 1942, is designed to elucidate the effect of various methods of surface preparation, weathering, pickling, &c., coupled in some cases with temporary protective treatments applied during the weathering period (corresponding to exposure on the stocks) before the painting proper. Data are given for the losses in weight and, in the case of as-rolled plates, for the percentage descaling of the steel as a result of this preliminary exposure. These show that for the general run of ships plates at least 6 months and probably much longer would be needed to remove the mill scale entirely by weathering; further, the weathering process is accompanied by the formation of substantial quantities of rust which cannot be removed completely from the surface by hand-cleaning.

All the temporary protective treatments tested, with the exception of mineral oil, were effective in eliminating rusting almost completely during the weathering period. Mineral oil had practically no protective effect and was markedly inferior to boiled linseed oil, which, when rubbed on thinly at the rate of about 3000 sq. ft. per gal., was found to protect the plates adequately during 70 days' exposure in the open at Caernarvon. Protection, however, is not the only criterion; it is equally important that the temporary protective shall be compatible with the final painting scheme. Interim results for the immersion tests proper show that the behaviour of one of the schemes used was adversely affected both by the boiled linseed oil film and by a temporary protective coat of red iron oxide paint (in an ordinary oil medium); on the other hand, the application of a tem-

porary protective coat of thin red lead paint, which dried out thoroughly during the weathering period, resulted in a pronounced improvement in performance. This again points to the necessity for complete control of the formulation of all paints used for marine purposes.

In the case of a moderately good painting scheme, better results were obtained both on as-rolled and on pickled surfaces that had been weathered for 105 days than on a freshly pickled surface, possibly because the presence of rust improved the adhesion of the paint. This may not be a general result, because with a better painting scheme which shows little deterioration to-date the reverse is the case, the freshly pickled specimens being the best of the batch.

Examination of specimens removed after 25 weeks' immersion showed that in all cases where the final scheme had been applied over surfaces from which mill scale had been incompletely removed by weathering, pitting had occurred at the boundaries of the remaining mill scale up to a depth of 0·034 in. Pickled surfaces suffered a different type of attack, which was localised to a shallow depth over comparatively large cellular areas, corresponding with places where the paint had flaked off. Since the tendency to pit will remain so long as the mill scale is incompletely removed, and since weathering in the yard and on the stocks cannot be relied on to bring about complete descaling, it is suggested that more attention be devoted to the use of pickling for this purpose.

Good agreement in assessing the protective values of the various painting schemes was observed between the results of the raft tests and those obtained in laboratory tests at the Chemical Research Laboratory, using a special apparatus in which specimens are rotated rapidly in sea water.

Series V., also begun in January, 1942, is concerned with new types of protective paints that are being developed by Dr. U. R. Evans. These are designed to overcome one of the fundamental disabilities associated with the protective painting of structural steel, namely, that all coats should be applied to a good surface under good conditions. It is hoped that these new paints will prove insensitive to these adverse factors and that they will be found to give good results when applied, for instance, to wet and rusty steel. Results so far are encouraging, and in tests of up to 6 months the protective properties of some of them have proved equal to those of the best commercial compositions.

Tests on a number of formulated compositions prepared by the Paint Research Station, through the courtesy of Dr. L. A. Jordan, are reported (Series VI.). These constitute an investigation of the possibility of substituting coumarone and lanolin for rosin and linseed oil, respectively, in media of the rosin/coal-tar-pitch/linseed-stand-oil type. These schemes failed rapidly by fouling, largely because the toxin contents of the anti-fouling compositions were too low, but the results showed that several of the schemes in the substitute media had promising protective properties.

This brings the account of the raft tests up to-date. An outline is given of the immediate experimental programme, which will consist of three interrelated series of tests on special compositions formulated and prepared by the Sub-Committee :

(1) Tests at Caernarvon, in which the pigmentation of the protective composition will be the main variable. This series has just been begun and a few details of it are given.

(2) Tests at Emsworth, where a new testing station will be set up by the Admiralty Corrosion Committee under the direction of Dr. I. G. Slater. Here the main variable will be the medium used for the protective compositions; a limited number

of alternative pigments will be put up in each medium. In addition, the effect of building up thick films of paint on the steel specimens will be systematically investigated.

In series (1) and (2) the same anti-fouling composition will be used throughout each series.

(3) Tests at Millport, by Dr. J. E. Harris, on anti-fouling compositions, in which a number of old and of possible new toxins will be tested in a variety of media.

All these series will be correlated with each other and with the results of accelerated laboratory tests at the Chemical Research Laboratory, Teddington, by means of suitable controls. In addition, storage tests, both at ordinary and at tropical temperatures, will be made to test the keeping properties of all the compositions prepared.

Section B concludes with an account of subsidiary series of tests relating to protective metallic coatings and to unprotected irons and steels, respectively.

Immersion tests at Gosport have shown that thin coatings of zinc—or aluminium—ranging up to 0·005 in. thick, protect steel adequately for at least one year (the tests are still in progress). Zinc coatings have a decidedly toxic effect as compared with aluminium, but this does not suffice to prevent fouling completely. Tests at Caernarvon in which paints were applied over the metallic coatings before immersion showed that the effect of zinc on fouling was evident even when the surface was painted over with three coats of naval compositions, finishing with an anti-fouling coat. The behaviour of this painting scheme was better over the metallic coatings than over bare steel, no doubt a result of the suppression of rusting; there was evidence, too, of better behaviour on a surface pickled by the Footner process, which includes a finishing dip in dilute phosphoric acid, than on a surface pickled by the normal Admiralty procedure in cold dilute hydrochloric acid.

Tests on bare irons and steels at Gosport and at Plymouth showed that, apart from the fact that Scottish wrought iron was about 15% more resistant to corrosion than ordinary mild steel, there was no appreciable difference in the losses in weight of numerous types of ordinary and low-alloy irons and steels of constructional quality when immersed in sea water in the bare condition. In particular, the presence of small amounts of copper, alone or in combination with small amounts of chromium, had no effect. This should be regarded as an interim result, but it is clear that any differences will be negligible when, as is imposed by necessity in service, the irons or steels are exposed with a protective coating.

Section C.—Anti-Fouling Investigations

The biological aspects of fouling are first considered. The community of organisms appearing on non-toxic surfaces includes marine bacteria, seaweeds, diatoms and sessile marine animals, such as barnacles, calcareous tubeworms, ascidians (sea-squirts), polyzoa, mussels and hydroids. The community can be resolved into fairly well-defined separate layers; from a basal carpet layer, a more complex community may grow up. The extent of this growth varies with the toxicity of the paint, with the season of immersion and with the organisms available to settle and able to maintain themselves in a community. The presence of some types of fouling impedes the settlement and growth of other types.

Different types of organisms differ widely in their sensitivity to the metallic toxins commonly used in anti-fouling compositions. This is demonstrated by the results, which have also been used to study

the effects of different toxin concentrations, differences in medium and other variables on the performance of specially formulated anti-fouling compositions.

The development of fouling, *i.e.*, the sequence in which the various types of organism appear on the surface and their relation to each other, is being studied. The earliest stage consists of a bacterial or diatom slime. This film has been observed to form on all anti-fouling paints exposed in the sea. The amount of slime bears a definite relationship to the toxicity of the paint and is also influenced by some of the ingredients in the paint medium. A quantitative method of determining slime formation has been developed, in which the film is stained with methylene blue; the dye-stuff absorbed is leached out and estimated colorimetrically. It is hoped to make use of this as a rapid means of determining toxicity, since the time necessary for the formation of slime is a few days only and much shorter than that required for the development of weed fouling. Moreover, slime formation is much less affected by the season, which should render it possible to conduct determinations all the year round without reference to the fouling season.

The diatom flora also provides a means of estimating the toxicity of a surface soon after its immersion in sea water, long before visible signs of fouling on a large scale appear; this method, too, should be capable of use at all times of the year.

Evidence shows that the toxicity of a surface has little effect on the growth of an organism once attachment has taken place. Possibly, attachment could be prevented by the incorporation in the anti-fouling composition either of substances that repel or kill the organisms in their settling stages or, alternatively, of substances which prevent the adhesion or setting of the cementing substance by means of which the organisms attach themselves. The second possibility is being explored with special reference to the cement secreted by the larva of the common barnacle, one of the most important organisms. This study has been greatly facilitated by the development of methods for rearing this animal in the laboratory from its free-swimming larval stage to its fixed stage.

Fundamental investigations of the principles underlying the action of anti-fouling compositions are in progress. These consist mainly of raft tests on formulated compositions, a large number of which, containing both inorganic and organic toxins, have been prepared.

In the case of the common inorganic poisons, it has been demonstrated that mercury is approximately twice as effective against weed fouling as copper (weight for weight); arsenic, at least in the form of arsenious oxide, is almost ineffective. The ratio of the effectiveness of mercury and copper is higher in the case of barnacle fouling, for which it is at least three to one; again, arsenic has little effect.

The anti-fouling effect of the usual copper compounds was primarily determined by their copper content and fell off in the following order: Copper bronze, cuprous oxide, copper thiocyanate, Paris green. The physical form and solubility of any given toxic pigment will also be of importance.

Numerous organic toxins have been tested, both in the laboratory and in the form of paint films on panels immersed in the sea. The laboratory tests consist in determinations of their toxic effects on marine organisms in sea-water cultures; under these conditions many of the compounds are at least as toxic as copper and some even more toxic than mercury. On the other hand, with a few promising exceptions, the toxicity of these compounds when incorporated in actual paint films has fallen far below the values that would be expected from the sea-water culture experiments.

Chemical studies of the rate of leaching of copper, mercury and organic compounds from paint films in sea water are in progress, and micro-analytical methods have been developed for this purpose.

The maximum effectiveness of the most suitable toxins, when they are discovered, will only be achieved by their incorporation in the most appropriate paint medium. This aspect of the matter is being studied, due regard being paid to the conflicting requirements that the toxins shall be readily and continuously available whilst the coating itself shall be as durable as possible.

Attempts are being made to ascertain the chemical mechanism by which toxins produce their anti-fouling action. To this end the chemical equilibrium between the copper pigment, the free fatty acid in the paint medium and the sea water is being investigated.

The importance of providing efficient protective undercoats is stressed. Statistical analysis of the correlation of fouling with rusting on a number of specimens coated with proprietary painting schemes showed that fouling always followed rusting. No evidence was obtained that the presence of fouling organisms on the specimens induced rusting.

Section C concludes with some notes on the results of the examination of upwards of sixty samples of fouling from ships. The number of species represented was fewer than is found on specimens exposed in raft tests, probably because of the more limited flora available for settlement in many ports compared with those in the vicinity of the rafts. Only certain seaweeds have spreading attachment systems and growth forms suitable to withstand the force of water movement over a ship's hull. Considerable progress might be made by concentrating attention on the elimination of the specific types of organisms chiefly responsible for fouling under practical conditions. This in turn suggests that anti-fouling formulations of the future will not be one but several, each specially designed for the special conditions of service of individual vessels. Practical developments in this direction will be materially facilitated by the planned co-operation of ship-owners, both in forwarding samples of fouling for examination and in providing facilities for tests on vessels.

Section A.—Introduction.

Part I.—Constitution of the Marine Corrosion Sub-Committee.

The Corrosion Committee of The Iron and Steel Institute and The British Iron and Steel Federation, under the Chairmanship of Dr. W. H. Hatfield, F.R.S., have been engaged for a number of years in a systematic study of the corrosion of iron and steel and of methods for preventing this. Corrosion arising as a result of immersion in sea water has naturally come under their attention, and their published Reports contain accounts of several investigations in this field. Additional impetus has been given to this branch of their work during the past two or three years by the desire, expressed by the Admiralty representatives and others, for a fundamental research into the prevention of fouling. Although

the possibility of using other methods should not be ignored, this is usually accomplished at present by means of anti-fouling compositions, and since, as will be evident from the present Report, the behaviour of an anti-fouling composition cannot be divorced from that of the anti-corrosive coat beneath it, the Committee decided that this was a pertinent enquiry for them to undertake. Accordingly the matter was referred to the Marine Corrosion Sub-Committee. They, in turn, strengthened their membership by co-opting various authorities on such matters as marine biology, paint technology and practical shipping conditions, whose experience has been of inestimable value in the Sub-Committee's deliberations, and in addition appointed a full-time investigator, Dr. J. E. Harris, to deal more specifically with the biological and anti-fouling aspects of their investigations.

As a result, the constitution of the Marine Corrosion Sub-Committee is now, February 24th, 1943, as follows:

Dr. G. D. Bengough, F.R.S. (*Chairman*)	Formerly of the Chemical Research Laboratory, Teddington.
Dr. W. R. G. Atkins, F.R.S.	The Marine Biological Association, Plymouth.
Dr. G. S. Baker	Shipbuilding Conference.
Dr. C. H. Desch, F.R.S.	The Iron and Steel Industrial Research Council.
Mr. F. Fancutt	London, Midland & Scottish Railway Co.
Mr. W. A. D. Forbes	The Admiralty.
Professor F. E. Fritsch, F.R.S.	University of London.
Dr. J. E. Harris (*Investigator*)	The Iron and Steel Institute.
Dr. H. W. Harvey	The Marine Biological Association, Plymouth.
Dr. J. C. Hudson (*Official Investigator*)	The Iron and Steel Institute.
Dr. L. A. Jordan	The Research Association of British Paint, Colour and Varnish Manufacturers.
Dr. J. Montgomerie	Lloyd's Register of Shipping.
Mr. R. H. Myers	The British Iron and Steel Federation.
Mr. V. G. Shepheard	The Admiralty.
Dr. I. G. Slater	H.M. Dockyard, Portsmouth.
Mr. C. Gordon Smith	Messrs. Alfred Holt & Co.
Dr. H. Sutton	The Royal Aircraft Establishment, Farnborough.
Dr. E. V. Telfer	N.E. Coast Institution of Engineers and Shipbuilders.
Mr. T. Henry Turner	London & North Eastern Railway Co.
Dr. W. H. J. Vernon	The Chemical Research Laboratory, Teddington.
Mr. A. E. Chattin (*Secretary*)	The Iron and Steel Institute.

PART II.—PRESENT POSITION AND OBJECTS OF THE SUB-COMMITTEE'S WORK.

The ultimate purpose of the Sub-Committee's work is to establish the most efficient and economic cures for the two evils that beset all ordinary irons and steels of construction when immersed in sea water—namely, corrosion and fouling. It is hardly necessary to refer to the detrimental effects of the latter on fuel consumption or alternatively on speed in the case of ships, a matter of prime importance both to naval vessels and to merchant ships, whilst the corrosion hazard is reflected in the appreciable margins of safety allowed in the thickness of hull plates. Although it is probable that the prevention of fouling is the major problem in the later stages of a ship's history, when the hull has become seasoned and has accumulated a thick coat of paint, the prevention of corrosion is of corresponding importance during its early life, both because serious damage may result from excessive attack and because, as will be shown later, the fouling problem cannot be solved if the hull is inadequately protected. Consequently, the ideal solution is to devise methods of preventing both evils right from the very start.

Revolutionary methods of dealing with the problem, such as, for instance, the prevention of fouling by poisoning all the organisms in a docking basin or repelling them by suitable electrical discharges, should not be regarded *a priori* as out of the question, but they are essentially matters for the future. For the time being the Sub-Committee have considered it wise to study and perfect the existing method. In essentials, this consists in applying a suitable protective coating to the steel plates to prevent them from rusting, over which in turn a toxic agent is applied to poison any fouling organisms that may try to settle on the surface. So far both the protective coating and the toxic agent have taken the form of paints, which are generally applied by brush, spraying not being in great favour in dockyards, for various reasons. It should not be assumed that this state of affairs will continue indefinitely. It can, for instance, be envisaged that at some time in the future new construction will receive a single coat of vitreous enamel or plastic material, sprayed on and stoved in position, with such suitable mechanical and other properties that it will form a protective coating lasting the life-time of a ship. So far as the prevention of fouling is concerned, it would already be possible, should such a course be considered desirable, to apply a thin sheath of metallic copper all over the hull. Admittedly these are flights of fancy, but it has to be remembered that present methods of dealing with the problem are largely governed by what is practicable under the existing methods of construction and maintenance. It is possible that one result of the introduction of prefabrication methods will be to increase considerably the range of protective coatings that can be applied to ships' plates, since it

will be possible to undertake the work in sections in the shops, instead of having to tackle the whole hull at once.

For the present, however, attention must be concentrated on the usual painting schemes, consisting of anti-corrosive (or protective) compositions followed by a final coat (or coats) of anti-fouling composition. There is plenty of scope for investigation here. The production of satisfactory paints is still very largely an art, no doubt partly because the raw materials of the paint trade, apart from pigments, are in the main complex organic substances of natural or synthetic origin, the properties of which are still imperfectly understood. The majority of ships' bottom compositions used in Great Britain are proprietary brands, the precise formulation of which is known only to their manufacturers. These brands vary considerably in performance—often for the good reason that they are intended for different types of service. This has the disadvantage that by buying compositions on the general reputation of particular manufacturers the user by no means ensures that he obtains even the best of the available paints for his particular purpose.

The immediate object of the Sub-Committee is, therefore, to establish, by experimental enquiry, formulations and specifications for ships' bottom compositions, both protective and anti-fouling, the suitability of which for use under given conditions will have been demonstrated by experimental test. It should be made clear that by " formulations " is understood not only precise details of chemical composition but such further information concerning physical constants of medium, pigment and anti-fouling materials, &c., as may be required to enable any qualified manufacturer to produce the materials successfully.

The necessary investigations to this end may be considered under two heads : (*a*) protection, (*b*) anti-fouling.

(a) *Protection.*—Compared with the prevention of fouling, the protection of a steel plate immersed in sea water against rusting by means of paint should be a simple problem. Its solution will probably be found to lie in combining a pigment with the requisite degree of inhibitive properties with an impermeable medium that is not hydrolysed or attacked by the slightly alkaline conditions of exposure to sea water.

Other problems of equal importance are the adhesion of the protective paint to the steel surface and the adhesion of the anti-fouling composition to the protective paint. The former will depend on the state and preparation of the steel surface, which in turn involves a study of the effect of the surface condition of the steel at the time when the paint is applied. Adhesion, or compatibility between the protective and anti-fouling compositions, can be dealt with by paying due regard to the formulation of both paints.

(b) *Anti-Fouling.*—The anti-fouling problem is a most interesting field of study, since its solution calls for the combined resources of

biology, organic chemistry, paint technology, metallurgy and other sciences, whilst when applying any such solution to practical ends due consideration must be paid to the requirements of naval architecture, shipping routine and economics. Methods of attack will be discussed later in this Report; they may briefly be recorded here.

(i) It is first necessary to establish what types of organisms are responsible for the fouling of ships under practical conditions.

(ii) The life-cycle of these organisms should be studied together with the sequence in which they establish themselves on a fouled surface, with a view to ascertaining how and when they are most susceptible to attack by poisons or repellants.

(iii) The effects of different poisons (toxins) on the individual organisms should be determined, with a view to selecting those toxins that are most effective in the case of the particular organisms that are responsible for the bulk of the fouling.

All these are matters for the marine biologist. In addition :

(iv) A search should be made for new and better toxins. Here the organic chemist should play an important part for two reasons : first, the toxins now commonly employed in anti-fouling paints are in the main oxides or simple compounds of arsenic, copper and mercury, the toxicity of which per unit weight of metal is well established or at least has a limiting value. The most promising source of compounds of higher toxicity is to be found in the field of organic chemistry. Secondly, two of the toxic metals, copper and mercury, particularly the latter, are expensive and, in wartime at least, in short supply. Since high concentrations of these are necessary to secure immunity from fouling under the worst conditions, it is most desirable to develop satisfactory substitutes for them. Here again the natural resort is to organic chemistry.

Finally the paint technologist and the physical chemist come into the picture, as follows :

(v) When the type of fouling organisms and the nature and the time of the attack to be made on them have been established, when the best toxins have been found, there remains the problem of so incorporating the toxins in a paint that their efficiency remains unimpaired, not only in the freshly-applied paint film but in the same film after it has been exposed to the rigours of the sea for several months (obviously the longer the better). The requisite formulation of the anti-fouling composition involves a delicate balance between medium, pigment

and toxin, necessitating for its most successful accomplishment the physico-chemical study of such phenomena as the diffusion of both water and toxins through the paint film, the degradation of the film and the surface reactions between the toxins and the sea water.

A few words may be added to explain what is meant by "due consideration to the requirements of naval architecture, shipping routine and economics." The implication is that any solutions of these problems ultimately reached must be capable of application under the practical conditions prevailing at present; there is a vast difference between applying a process satisfactorily to a small steel plate exposed on a raft and to a 10,000-ton ship in dry-dock. The methods of assembly used in naval architecture affect the problem; for instance, the use of welding renders it undesirable to paint the edges of plates before they have been fixed in position. Shipping routine, too, makes certain obvious demands; clearly, no process involving delay in dry-dock would be enthusiastically received. Lastly, economic considerations must remain the final criterion, since it is obvious that the cost of any process suggested must bear a favourable relationship to the benefits accruing from its use.

Contents of this Report.

The earliest experimental work of the Sub-Committee was undertaken in collaboration with the Admiralty Corrosion Committee and consisted in comparative trials of various proprietary naval compositions. These trials took the form of raft tests on specimens of painted ships' plate exposed at Plymouth and Caernarvon. Raft tests, under the care of Dr. J. C. Hudson, are now playing an important part in the development and testing of paints of known composition as part of the Sub-Committee's systematic search for reliable compositions of stated formulation. It will be convenient to consider the various series of raft tests together and they form the subject of Section B, which follows the present introductory Section A.

Section C is devoted to a description of the anti-fouling investigations proper, with particular reference to the biological line of attack, which are being conducted by Dr. J. E. Harris. This should be regarded as an interim statement, mainly intended to indicate the directions in which the researches are progressing rather than to set out in detail the results so far achieved.

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Ben Line Steamers, Ltd.
Blue Star Line, Ltd.
Messrs. C. T. Bowring & Co., Ltd.
British India Steam Navigation Co., Ltd.
British Tanker Co., Ltd.
Messrs. Thos. & Jno. Brocklebank, Ltd.
The China Navigation Co., Ltd.
City Line, Ltd.
Joseph Constantine Steamship Line, Ltd.
Cunard White Star, Ltd.
Messrs. R. S. Dalgliesh, Ltd.
Eagle Oil & Shipping Co., Ltd.
Ellerman & Bucknall Steamship Co., Ltd.
Ellerman & Papayanni Lines, Ltd.
Messrs. James Fisher & Sons, Ltd.
Messrs. Furness, Withy & Co., Ltd.
General Steam Navigation Co., Ltd.
Hall Line, Ltd.
Messrs. H. Hogarth & Sons.
Messrs. Alfred Holt & Co.
Messrs. Houlder Bros. & Co., Ltd.
London, Midland and Scottish Railway Co.
Messrs. H. E. Moss & Co.
Moss Hutchison Line, Ltd.
New Zealand Shipping Co., Ltd.
Orient Steam Navigation Co., Ltd.
Pacific Steam Navigation Co.
Peninsular and Oriental Steam Navigation Co.
Port Line, Ltd.
Royal Mail Lines, Ltd.
Messrs. Chr. Salvesen Co.
Messrs. W. H. Seager & Co., Ltd.
Shaw Savill and Albion Co., Ltd.
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Ltd.), for the provision of the not inconsiderable quantities of steel specimens and frames required for these investigations, and to the Harbour Master and Trustees of the Port of Caernarvon for the provision of exposure facilities at that port. Finally, as a result of their collaboration with the Admiralty Corrosion Committee, they have enjoyed, particularly in the early days of the investigation at Plymouth, considerable assistance in services and in kind from Admiralty Shore Establishments, which is acknowledged with appreciation.

The Sub-Committee wish to put on record their warm thanks to Dr. W. H. Hatfield, F.R.S., Chairman of the Corrosion Committee, for the great help that he has given them from time to time.

Section B.—Raft Tests.[1]

By J. C. HUDSON, D.Sc. (Official Investigator).

Part I.—Introduction.

The Sub-Committee's earliest series of raft tests on ships' bottom compositions were concerned with comparative trials of proprietary paints, undertaken at the request of the Admiralty. In many cases the compositions of these paints were unknown, except in so far as they could be ascertained by analysis. It is not permissible in a Report such as this to refer to proprietary brands by name; in any case such reference would serve no useful purpose, since it cannot be assumed that the composition of any given brand remains constant. Consequently no attempt will be made here to compare the products of rival manufacturers. The method of approach will be rather to consider the results as a whole and to deduce from them such generalisations as may bear usefully on the more constructive scientific work of the Sub-Committee to which these earlier tests have given rise.

In brief, this later work has the object of establishing the formulations of compositions, both protective and anti-fouling, that will be purchasable to specification and have a performance in service equal to or better than the present run of commercial compositions. This involves tests on numerous paints of known composition, specially prepared for the purpose. In conjunction with this work studies have been undertaken of the effect of the surface condition of the steel and of other variables on the adhesion and behaviour of ships' bottom compositions. This knowledge is necessary to ensure that maximum performance is obtained from the

[1] Received November 6, 1942.

compositions, and is of particular importance in the case of new construction.

TABLE I.—*Summary of Raft Tests to Date* (*September*, 1942).

Series.	Date Commenced.	Station.	Nature of Tests.	Number of Specimens.
I.	March, 1940	Plymouth	Proprietary compositions	72
II.	May, 1941	Caernarvon	,, ,,	96
III.	July, 1941	,,	Paints over metallic coatings, &c.	24
IV.	Jan., 1942	,,	Effect of surface condition	106
V.	,,	,,	New-type protective paints (Dr. U. R. Evans)	12
VI.	,,	,,	Formulated compositions (Paint Research Station)	42
VII.	Sept., 1942	,,	Formulated protective compositions. Effect of pigment.	188
...	,,	,,	New-type paints (Dr. U. R. Evans)	12
...	,,	,,	Effect of surface condition	54
III.	,,	,,	Paints over metallic coatings, &c. Repainted	10

The various series of tests that have been undertaken to date are summarised in Table I. They will be considered in order, as follows:

Part II.—Experimental Procedure.
Part III.—Series I. and II. Tests on Proprietary Compositions at Plymouth and Caernarvon.
Part IV.—Series IV. Effect of Surface Condition.
Part V.—Series V. New-Type Protective Paints (Dr. U. R. Evans).
Part VI.—Series VI. Compositions Formulated by the Paint Research Station (Dr. L. A. Jordan).
Part VII.—Immediate Experimental Programme.
Part VIII.—Series VII. Effect of Pigment in the Protective Paint.
Part IX.—Other Test Series.

It should be noted that Series III. (paints over metallic coatings) is not dealt with in the correct numerical sequence; the tests concerned are discussed in Part IX. (other test series).

The preparation, inspection and final examination of the specimens for this experimental programme has involved much work, the magnitude of which may be gauged from the facts that painting and immersion alone at the testing station involves 2·9 man-hours per specimen and the full complement of the Caernarvon rafts is now 348 specimens. The successful accomplishment of this considerable undertaking has been rendered possible by pooling the

resources of several laboratories and, in particular, by the enthusiastic collaboration of the following :

Dr. T. A. Banfield and Mr. H. A. Holden	Corrosion Laboratory, Birmingham.
Mr. L. Kenworthy, Mr. E. J. Hammersley, Mr. L. N. Parr and Mr. A. Partington	Admiralty Metallurgical Laboratory, Emsworth.
Mr. F. Goodier	Paint Research Station, Teddington.
Mr. F. G. Dunkley, Mr. D. G. Soar and Mr. F. D. Timmins	Paint Laboratory, L.M.S. Railway Research Department, Derby.

Thanks are also due to Dr. W. R. G. Atkins, F.R.S., who kindly undertook the inspections in the Plymouth tests, and to Dr. J. E. Harris, who assisted with the earlier inspections at Caernarvon.

Part II.—Experimental Procedure.

Apart from minor modifications, introduced as a result of experience, the experimental procedure in all tests has been as follows :

(1) *Specimens.*

The specimens used are of ordinary ships' plate quality steel, sawn or sheared to size 15 in. × 10 in. The thickness in the earliest series was $\frac{3}{8}$ in.; this has since been reduced to $\frac{1}{4}$ in. The edges and corners are rounded. All tests are made in duplicate.

(2) *Surface Preparation.*

The surface preparation of the steel before painting varies according to the nature of the tests. For instance, in series I. both specimens were pickled in cold 5% (by volume) hydrochloric acid, the standard Admiralty procedure, but in series II. one specimen of each pair was repainted over old paint. In later series, various weathering and temporary protective treatments have been used.

(3) *Painting.*

With few exceptions, all painting schemes tested consist of two coats of anti-corrosive and one coat of anti-fouling composition, *i.e.*, three coats in all. All specimens are painted by hand under cover, using 2-in. bristle brushes, except where special methods are necessary. The atmospheric temperature and relative humidity at the time of painting are noted, but no effort is made to control them. The weight of each coat of wet paint is determined and in the case of the anti-corrosive coats that of the dry paint film also. As a rule, the amount of paint applied is left to the discretion of the painters, who endeavour to put on a reasonable and adequate coating.

Painting is conducted according to a pre-arranged schedule, which allows for 24 hr. at least between successive coats and for a stipulated interval, not less than 4 hr. and usually about 6 hr., between the application of the anti-fouling composition and immersion.

In some tests, a small area or "holiday," generally a square of ½ in. side, is left unpainted on both sides of a specimen. This is done to ascertain how far the corrosive attack of the sea water is concentrated at the bare areas; the result depends on the nature of the paint protecting the remainder of the surface and varies from one painting scheme to another.

(4) *Exposure.*

The method of exposing the specimens is shown in Figs. 13 and 14. The specimens are bolted to the frames by steel bolts, which pass through insulating sleeves of Bakelite composition. When in position the specimens are immersed vertically at a depth of approximately 18–24 in. to the top edge of the specimens. Recently, double frames have been introduced, carrying a second row of specimens 18 in. below this. The conditions of immersion thus resemble those of ships' plates two or three feet below the light-load line. The clearance between adjacent frames is now approximately 1 ft. 5 in. and was rather greater in the earlier test series.

Two rafts have been used. The first was built for the tests at Plymouth by the Constructive Department, H.M. Dockyard, Devonport, and was 36 ft. × 22 ft. overall. It was made of 12-in. square baulks, which gave the necessary buoyancy. During the tests the raft was moored just inside the breakwater at the entrance to Plymouth Sound.

The second raft (Fig. 14), in use at Caernarvon, was purchased by the Sub-Committee when it became impracticable to continue tests in Plymouth Sound. The design is similar to that of the Admiralty raft, save that buoyancy is mainly obtained from drums, and fairweathers [1] are fitted fore and aft. The full complement of the Caernarvon raft is 300 specimens, carried on 25 single and 25 double frames.

The Caernarvon raft is moored in the Menai Straits, just to the West of the river mouth at Caernarvon, in a depth of water of 3–4 fathoms at low water, ordinary spring tides. The spring tidal rise is about 16 ft. The tide is about 1½–2½ knots at neap tides and 3½–5 knots at spring tides, but the raft is not in the main tideway. Its axis lies approximately N.E. to S.W.

In order to permit of the beaching of the exposure raft for cleaning and overhaul, a smaller subsidiary raft has been built, to which specimens are transferred for the relatively short period required. This smaller raft can be used, during the periods between

[1] Not shown in the photograph.

the overhauls, to carry 48 specimens, which are exposed in the same manner as the others.

To minimise any positional effects over the raft, of which slight evidence has been observed at times, care is taken when allocating the specimens to the frames to ensure that each member of a pair is in a different half of the raft. Otherwise, so far as is practicable, the allocation of the specimens is at random.

(5) *Inspections.*

Inspections are generally made at intervals of about 4–6 weeks. The frames are lifted in turn and the condition of each specimen is noted. Records of the fouling and the physical deterioration of the paint film are kept separately for the front and back. Standard forms are used.

Items, such as fouling (slime, weed, shell, &c.) or chalking of the paint film, which cannot be assessed on a strictly quantitative basis, are expressed as grades, ranging from 1 to 7, each of which has an agreed significance. Flaking, blistering and rusting are returned as the percentage of the total area that is affected by each particular defect.

Assessment is often rendered difficult by the fact that premature failure occurs at the edges of the specimens. This may be associated with the shearing or sawing of the plates. The expedient of adding an additional preliminary coat of protective composition in the form of a narrow band round all edges has been tried but does not overcome the difficulty. Consequently, in the latest tests, inspections have been made through a mask, covering a border about 1 in. wide all round the edges.

The system of grading used is only a convenient form of recording and correlating the observations; in order to render them readily intelligible to the general reader they will be converted, where possible, into terms of the useful life of the composition concerned. By this is understood the duration of immersion until failure occurs, *i.e.*, the stage is reached at which repainting would be desirable under practical conditions on a ships' hull. The grades or combinations of grades representing this condition were agreed on at an inspection of the Caernarvon specimens made by the Sub-Committee as a body in September, 1941.

(6) *Final Examination.*

All tests are quantitative, *i.e.*, the specimens are weighed at all stages of preparation. After exposure, fouling is removed at the exposure station, before the specimens are returned to the laboratory. Here, they are cleaned by bristle brushes under running water, dried and reweighed. Then the surface is examined and the percentage of intact paint left is determined. If no repainting test is to be made, the residual paint is often removed by treatment

with caustic soda solution; this enables the weight of steel lost by corrosion to be determined directly.

Notes are taken of the positions and depths of any pits and of the depth of penetration at any holidays.

Part III.—Series I. and II. Tests on Proprietary Compositions at Plymouth and Caernarvon.

Two series of tests on proprietary compositions have been made. The first was begun at Plymouth in April, 1940, and the second at Caernarvon in May, 1941. For both tests, twenty-three firms of paint manufacturers submitted samples at the invitation of the Admiralty; in some cases more than one set of samples was sent, whilst the Sub-Committee added a few paints of their own at Caernarvon, with the result that the total number of painting schemes tested at Plymouth was 35 and at Caernarvon 47. Twenty-three schemes were common to both series. Single sets of bare pickled steel specimens were immersed alongside the painted ones, bringing the total number of specimens to 72 at Plymouth and 96 at Caernarvon.

(a) *Experimental Details.*

(1) *Plymouth.*

The 35 three-coat painting schemes were applied to duplicate specimens of freshly pickled steel; holidays, $\frac{1}{2}$ in. square, were left on both surfaces of one specimen of each pair. The specimens were immersed on March 19–20, 1940. Monthly inspections were made in April and May, but owing to emergency conditions at Plymouth no further inspection was possible until October, 1940, when the raft was towed back to the Dockyard. A final inspection in position was then made before the specimens were removed; they had been immersed for 29 weeks.

(2) *Caernarvon.*

The old Plymouth specimens were used again at Caernarvon. At the conclusion of the Plymouth test the paint had been stripped from the specimens with the holidays; the duplicates had been cleaned only, leaving on any adherent paint. Prior to repainting at Caervarvon, the first specimen of each pair was given a light repickle in warm dilute sulphuric acid, so as to produce a clean metallic surface; in the other case the new paint was applied directly over the old after this had been lightly wire-brushed. Holidays were again left on both surfaces of the pickled specimens; these did not coincide with the old ones, which were painted over. The additional 24 specimens required, as compared with the Plymouth tests, were obtained from dummy specimens which had

been painted with three coats of naval compositions and immersed alongside the specimens proper at Plymouth for several months.

The specimens were immersed on May 12–14, 1941, and were inspected regularly at intervals of 4 weeks. In November, 1941, after 26 weeks' exposure, 80 of them had deteriorated so badly that they were removed together with the 2 unpainted specimens. The test on the remaining 14 specimens was continued until July, 1942, when they had been immersed for 62 weeks.

(b) *Formulation and Consistency of the Paints Tested.*

(1) *Formulation.*

All compositions tested were analysed either by the Principal Chemist, H.M. Dockyard, Portsmouth, or by the London and North-Eastern Railway Laboratory, Doncaster. The general fre-

TABLE II.—*Constitution of Proprietary Ships' Bottom Compositions : Media and Pigments.*

Media.		Pigments.[1]	
Type.	Frequency. %.	Type.	Frequency. %.
Resin-oil . . .	53	Red iron oxide . . .	23
Resin	22	Red iron oxide, extended with whiting or barytes . .	6
Resin-oil-bitumen . .	11	Red iron oxide + zinc oxide.	23
Resin-wax . . .	5	Zinc sulphide white composite pigment (zinc oxide + zinc sulphide + barytes) . .	19
Bitumen-oil . . .	5	Zinc oxide, alone or extended with barytes . . .	9
Chlorinated rubber . .	4	Aluminium powder . .	4
		Miscellaneous mixtures[2] .	13
		None, other than toxins .	4
Total . . .	100	Total . . .	101

[1] Other than toxins.

[2] For instance, zinc dust, white or red lead, calcium sulphate or phosphate, alone or in combination with each other or the other pigments.

quency of the use of various types of pigments, media and toxins, which is of interest as representing present commercial practice in the formulation of ships' bottom compositions, is indicated in Tables II. and III.; in the former both protective and anti-fouling compositions are included.

Resin-oil media are by far the most common and are used in more than half of the compositions. Bitumen enters into 16% of them, but chlorinated rubber is present in only 4%. Red iron oxide and zinc oxide are the most popular pigments and are major

constituents of 80% of the paints. The toxin contents and the nature of the toxins used in the anti-fouling compositions vary widely and range from a minimum content of 5·0% to a maximum of 51%; these figures are the total percentage of the usual metallic toxins based on copper, mercury and arsenic, expressed as Cu, Hg and As_2O_3. In addition to these, a few compositions contain organic toxins, the use of which will probably extend. The overall average toxin content of all compositions tested was Cu 12·4%, Hg 4·8%, As_2O_3 5·3%.

TABLE III.—*Toxin Contents of Proprietary Ships' Bottom Compositions.*

Frequency. %.[1]					
Copper (Cu). %.	Mercury (Hg), %—				Total.
	<5.	5–9.	10–14.	15–19.	
<5	15	4	1	...	20
5–9	16	7	...	...	23
10–14	7	8	...	1	16
15–19	16	7	...	3	26
20–24	3	7	1	1	12
25–29	...	3	...	...	3
Total	57	36	2	5	100

[1] Arsenic was also present in 67% of the compositions, in amounts ranging up to 30·0% (calculated as As_2O_3).

Surveying these results as a whole, it is clear that there is much divergence of opinion between individual paint manufacturers as to the desirable constitution of ships' bottom compositions, particularly as regards medium and pigmentation—the toxin content is largely determined by the permissible selling price. It is desirable to eliminate this uncertainty and reduce ships' bottom compositions to a few tested formulations of known performance, incorporating the best combinations of medium, pigment and toxins.

(2) *Consistency.*

No attempt was made to control the weights of the various compositions applied to the specimens; they were used exactly as supplied by the manufacturers. There were striking variations in the consistency of the different samples, and it is fair to state that between one-quarter and one-half of them were not in the optimum consistency for application by short-handled brushes; a few were too thick, but more were too thin. After making due allowance for the facts that compositions for application by long-handled strikers, as in practice, need to be of thinner consistency than if they were

brush-applied, and that some paints may have thickened in storage, the conclusion remains that either insufficient attention has been paid to the question of consistency or that views on what is desirable vary considerably.

This variation in paint consistency is illustrated in Table IV., which gives the weights of dry paint, total for three coats,[1] (*a*) for

TABLE IV.—*Series I. and II. Proprietary Compositions. Analysis of Coating Weights. Total Dry Paint (Three Coats).*

Coating Weight. Oz. per sq. ft.	Number of Schemes.			
	All Schemes.		23 Schemes only.	
	Plymouth.	Caernarvon.	Plymouth.	Caernarvon.
0·3–0·4	4	8	3	5
0·4–0·5	6	12	4	9
0·5–0·6	5	8	3	4
0·6–0·7	10	5	6	2
0·7–0·8	4	2	2	...
0·8–0·9	3	1	3	...
0·9–1·0	1	1	1	...
>1·0	2	6	1	3

all the painting schemes at Plymouth and Caernarvon, respectively, and (*b*) for 23 painting schemes, that, except for a variation in one coat in a few cases, were of substantially the same formulations at Plymouth and Caernarvon. The overall variation in coating weight was from 0·37 to 2·03 oz. per sq. ft. at Plymouth and from 0·33 to 1·53 oz. per sq. ft. at Caernarvon.[2] The average value for all paints was less at Caernarvon than at Plymouth. This difference is probably connected with the personal element, since the respective pairs of painters were not the same, rather than with the prevailing temperature, which ranged from 48° to 60° F. at Plymouth and from 45° to 57° F. at Caernarvon.

The variation in the thickness of the paint films is less pronounced than is indicated by the coating weights, since these are affected by the marked differences in the specific gravities of the pigments used. Approximate calculations show that, in the case of nine painting schemes for which the necessary data are available, the total thickness of the two anti-corrosive coats varied from 1·1 to 3·3 mils. These values are lower than is common for paints used for atmo-

[1] The weights of the two anti-corrosive coats are determined directly; that of the anti-fouling coat is calculated from the observed weight of wet composition applied and the analytical figure for the percentage of non-volatile matter, allowing 5% loss on painting.

[2] The maximum figures refer to compositions brushed on cold; they were exceeded in the case of a composition formulated for hot-application.

spheric work or for compositions applied to ships' hulls under practical conditions (*see* Section B, Part III.(*j*)). The main reason is that, owing to the high percentage of volatile solvents in marine paints, sometimes 40% by weight or more, it is difficult to apply thicker coats when using 2-in. brushes.

Although film thickness is a function of the brushability of a paint, which in turn is largely determined by the constituents (*e.g.*, lamellar pigments will tend to brush out better and give thinner films than non-lamellar ones), wide variations in film thickness from one paint to another, insofar as they may arise from non-optimum use of thinners or other controllable variations in formulation, are undesirable, particularly in comparative tests on proprietary products. It is probable that several of the samples included in these tests would have given much better performance had they not been excessively thin. In general terms, provided that drying properties are not unduly sacrificed, the thicker the coating that can be applied in one operation the better. Some indication of the effect of coating thickness may be gathered from the data given in Table V. Here, owing to the personal factor, there was a

TABLE V.—*Series IV. Caernarvon. Effect of Coating Weight on Protective Properties.*

Paint.	Number of Specimens Coated by Each Painter.	Painter *X*.		Painter *Y*.	
		Average Total Weight of Wet Paint. Oz. per sq. ft.	Rust. %.	Average Total Weight of Wet Paint. Oz. per sq. ft.	Rust. %.
A .	25	0·83	2·7	0·74	3·9
P .	18	1·05	4·7	0·91	5·9
C .	9	1·10	0·11	0·92	0·13
B .	4	1·49	0·30	1·38	0·10
D .	3	0·71	3·9	0·62	3·0

systematic difference between the weights of paint applied to duplicate specimens by different painters. As the test proceeded, inspection showed that the specimen with the heavier coating was usually the better of each pair. The figures given refer to the average percentage of rust observed on the specimens after 20 weeks' immersion. The thicker coatings have given better results for the poorer paints *A* and *P*, whilst paint *C* resists corrosion sufficiently well even in the thinner film to prevent any difference from being apparent. The anomaly in the cases of paints *B* and *D* is probably due to the number of specimens being too small for accurate comparison. It should be added that steps are taken in the Sub-Committee's tests to reduce the effect of such personal factors on the results to a minimum.

In view of these observations it is desirable that some study be

devoted to establishing the optimum consistency of ships' bottom compositions, with due regard to differences in type and to practical conditions of application in dry-dock. The Sub-Committee propose to conduct suitable experimental work to this end.

(c) *Observations During Exposure.*

The following is a brief account of the development of fouling and rusting observed during the periods of immersion.

(1) *Plymouth.*

During the first two months, May and June, fouling was confined almost exclusively to slime and weed, but at the final inspection after 29 weeks most of the specimens were appreciably fouled by algæ, hydroids and shell (*see* Fig. 15). The shell was confined to mussels and calcareous worms. No barnacles were present. On some specimens ascidians were observed. In many cases the heavy fouling was associated with marked breakdown of the paint film, the protective composition or even the bare metal being exposed as a result of severe flaking.

Blistering, cracking or flaking of the paint film was evident on some of the specimens after two months' exposure; in the worst case more than 50% of the paint had flaked off. This deterioration of the paint had reached an advanced stage on many specimens when the tests were concluded after 29 weeks' exposure. Rusting was evident in numerous cases and was particularly noticeable at holidays which had been left on one specimen of each pair; here the rust deposit over these areas was often more than $\frac{3}{8}$ in. thick.

(2) *Caernarvon.*

Breakdown of the worst painting schemes occurred rapidly and rust was evident on some specimens at the first inspection after 4 weeks; 80% of the specimens had reached or passed the point of failure, either by rusting or by fouling, after 26 weeks' immersion, and they were removed then.

Owing to more frequent inspections, it was possible to study the development of fouling in greater detail than at Plymouth. The following are the chief features of the observations.

(i) *Types of Fouling.*—All types of fouling occurred, weed, hydroid and shell, including barnacles, calcareous tubeworms and mussels, as well as slime composed of microscopic and animal types. On the more badly fouled specimens ascidians, polyzoa and sponges were also found. All the foregoing are taken into account when assessing the performance of a painting scheme, except slime.

These remarks may be illustrated by the photographs reproduced in Fig. 16, which show the appearance of specimens painted with two of the best schemes at the time of their removal after 62 weeks'

immersion; the fouling is patchy and an appreciable area is still unaffected in both cases.

(ii) *Seasonal Effect.*—The different types of fouling did not develop simultaneously, as will be clear from Fig. 1. Weed developed throughout the whole period, but hydroids were first observed at 13 weeks. The development of shell fouling was anomalous. It settled on the specimens late in the season, the maximum occurring in October, just before the last inspection. Probably the test did not start early enough to include the first heavy fouling by certain

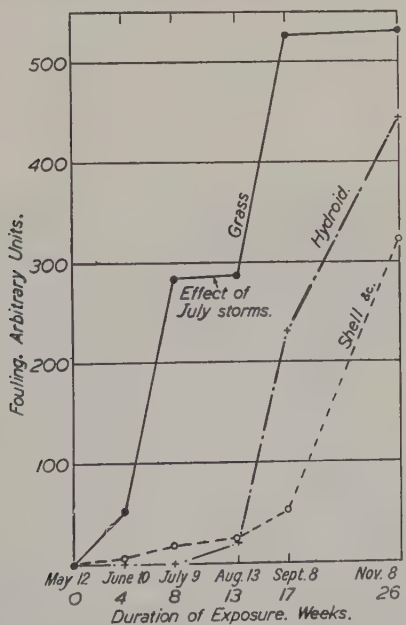


FIG. 1.—Series II. Caernarvon. Seasonal variation of fouling by weed (grass), hydroid and shell.

species, since it was noted that parts of the raft were heavily fouled with barnacles when the specimens were exposed on May 12. Sporadic settlement of shell went on throughout the whole test period.

(iii) *Effect of Light.*—Plant fouling (weed and most of the slime) develops most rapidly in light situations, whereas animal fouling (shell and hydroids) tends to develop in darker positions. This difference was reflected in the experimental results. It was found, as shown in Table VI., that the specimens carried relatively more weed fouling and relatively less animal fouling on their S.E. than on their N.W. surfaces, which received less sunlight than the former.

(iv) *Positional Effect.*—As all specimens are duplicated in different positions, the effect of position, if any, on the final results is minimised. One gross positional effect was, however, noted in August, 1941. The weed fouling on the specimens in the second bay of the raft decreased during the period July 9 to August 13, whereas that on the specimens in the third (centre) and fourth bays increased, though less than was expected.[1] Two factors may

TABLE VI.—*Series II. Caernarvon. Effect of Light on Fouling.*

Surface Facing—	Total Fouling. Arbitrary Units.		
	Weed.	Hydroids.	Shell.
N.W. . . .	768	398	235
S.E. . . .	909	295	185

have influenced this result; both depend on the effect of the tidal current, which runs S.W. during the falling tide and N.E. with the rising tide. The falling tide brings down much floating weed and other debris. This accumulated in the first (N.E. end) bay of the raft, and in July, when the weather was very stormy and the amount of drift weed correspondingly increased, the debris encroached even on the second bay. Since the accumulation of debris at the S.W. end was derived from a tidal current coming in from the open sea, it was much less and was confined to the end bay.

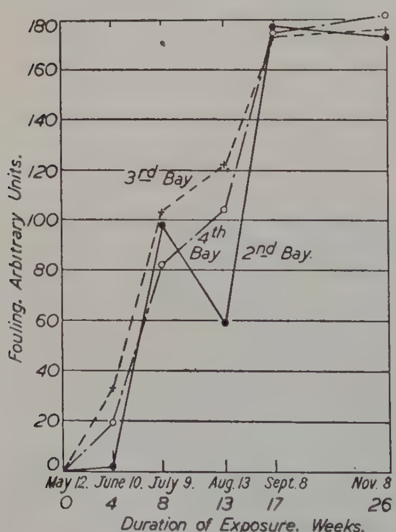


FIG. 2.—Series II. Caernarvon. Effect of position in the raft on weed fouling.

These mats of debris shielded the underlying specimens from the light and therefore killed the weed on the panels, or at least reduced its rate of growth. In addition, weed may be removed by the scouring action of the current, which in stormy periods carries considerable amounts of sand. The effect of both these factors is reflected in the results shown in Fig. 2 for the seasonal variation in weed fouling in each of the three bays.

It should be added that

[1] It will be seen from Fig. 14 that the raft has five bays. In these tests the three middle bays were used.

these observations were made before fairweathers were fixed to both ends of the raft at the end of 1941. These have largely eliminated these disturbing effects of the tidal currents.

(d) *Reproducibility of Results.*

The main object of the tests was to classify the proprietary compositions concerned in order of merit. This was done and, on the basis of their performance, the compositions were graded into categories "Very good," "Good," "Moderate" and "Bad," as regards (*a*) general behaviour, (*b*) anti-fouling properties alone and (*c*) protective properties alone. Details of the classification cannot be given, but it is of interest to note that the orders of merit deduced from each series of tests considered separately were substantially the same. This is illustrated by the results in Table VII., where

TABLE VII.—*Series I. and II. Comparison of the Gradings (General Performance) at Plymouth and Caernarvon.*

Plymouth.		Grading at Caernarvon.			
Grading.	Number of Schemes.	Very Good.	Good.	Moderate.	Bad.
Very good . .	1	...	1	...	...
Good . . .	4	1	1	2	...
Moderate . .	5	...	1	2	2
Bad . . .	13	1	...	...	12

the general classifications at Plymouth and Caernarvon are compared for 23 painting schemes that were essentially the same in both series.[1] At Plymouth ten schemes were graded as moderate or better; of these, eight were also graded as moderate or better at Caernarvon. On the other hand, only one scheme rated as bad at Plymouth was in the ranking list at Caernarvon, actually as very good; this difference could legitimately be attributed to the fact that the sample used at Caernarvon was of much thicker consistency and gave a much heavier coating.

Further evidence will be given later to support the conclusion that raft tests of this type are sufficiently reproducible for practical purposes.

(e) *Effect of Repainting.*

In the Caernarvon tests, all painting schemes were applied both to freshly pickled steel and over old paint. The lives to failure were estimated separately for each type of surface. A summary

[1] Twelve of the 35 proprietary compositions exposed at Plymouth either were not retested at Caernarvon or their formulation was altered substantially.

TABLE VIII.—*Series II. Caernarvon. Lives of the Painting Schemes.*

Life. Weeks.	Number of Schemes.[1]		
	Repainted Specimens.	Pickled Specimens.	Repainted Specimens. Fouling only.[2]
56–60	1	...	2
51–55	1	...	...
46–50	1	...	1
41–45	1	2	1
36–40	4	...	4
31–36	...	...	...
26–30	2	2	1
21–25	7	4	6
16–20	4	3	2
11–15	14	11	12
6–10	6	13	2
1–5	2	8	2

[1] The total is 43, the other four sets being those in which the drying period in air of the anti-fouling composition was varied from the normal (*see* Table XI.).

[2] Excluding cases of failure by rusting.

of the results is given in Table VIII. This shows distinctly that the performance of the compositions as a whole was better on the repainted specimens. The average life on pickled steel was 10·7 weeks, as compared with 16·2 weeks on repainted surfaces. As will be seen from Table IX., the ratio of the life over the old paint

TABLE IX.—*Series II. Caernarvon. Ratio of Lives of Compositions on Repainted and on Pickled Steel.*

Ratio. %.	Number of Schemes.	Ratio. %.	Number of Schemes.
<50	1	151–175	3
51–75	2	176–200	6
76–100	10	201–225	5
101–125	5	226–250	3
126–150	2	>250	6

to that on pickled steel exceeded 100% for 30 of the 43 painting schemes; also, the ratio varied considerably, in conformity with the fact that several of the worst painting schemes at Plymouth gave improved results in relation to the others when applied over old paint at Caernarvon.

The cause of failure differs markedly for the two types of surface, as shown in Table X. Of the repainted specimens coated with schemes ranked as moderate or better, 26 surfaces failed by fouling but

only three by rusting. For pickled surfaces the position was reversed, 14 failures being due to fouling and 18 to rusting. The specimens coated with bad schemes show the same general tendency.

These facts have an important bearing upon the interpretation of raft test results. It is clear that the behaviour of an anti-fouling composition is profoundly affected by that of the protective

TABLE X.—*Series II. Caernarvon. Causes of Failure of Compositions.*

Category.	Cause of Failure. Number of Surfaces.			
	Repainted Specimens.[1]		Pickled Specimens.	
	Fouling.	Rusting.	Fouling.	Rusting.
Moderate or better	26	3	14	18
Bad	30½	23½	17	37
All surfaces	56½	26½	31	55

[1] Three repainted surfaces did not fail within the test period. The "halves" result from the fact that one surface failed simultaneously by fouling and by rusting.

composition beneath it, and that, unless the latter confers adequate protection to the basis steel, full justice may not be done to the properties of the anti-fouling coat. Further, it may be postulated that the performance even of an indifferent protective scheme will improve as a thick film of paint is built up on the plates by successive repaintings. Coupled with this is the fact that in normal times ships may be in commission for twenty years or more, with the result that repainting over thick old paint is much more common than painting over bare or comparatively bare steel. Consequently, the results of these series of raft trials will be taken by the Sub-Committee as applying more particularly to new construction and the early stages of a ship's life, when corrosion is most frequently encountered. Information concerning the behaviour of compositions as applied over old paint on a seasoned ship will be sought by means of repainting tests to be undertaken as described later (*see* Section B, Part VII.(*d*)).

(f) *Anti-Fouling Properties.*

(1) *Life of the Anti-Fouling Compositions.*

It is clear from the previous remarks that resistance to fouling is best assessed on repainted specimens. For 33 of the 43 [1] specimens exposed at Caernarvon it was possible to determine the life to failure by fouling; the other specimens failed by rusting. These

[1] *See* Table VIII., footnote No. 1.

lives are summarised in Table VIII.; they ranged from 5 to over 56 weeks and averaged 22·6 weeks. In terms of life under service conditions, these figures should be multiplied by some suitable factor, say two or three, because the conditions to which raft specimens are exposed are more stringent. The timbers and drums of the raft soon foul and thereafter act as a source of contamination, whilst the deterrent effects on growth associated with high speed of motion through the water and often with transit from port to the open sea are entirely lacking.

(2) *Effect of Toxin Content.*

The effectiveness of an anti-fouling composition will vary with the nature of the toxins employed, their concentration in the paint film and the physico-chemical relationship between them and the

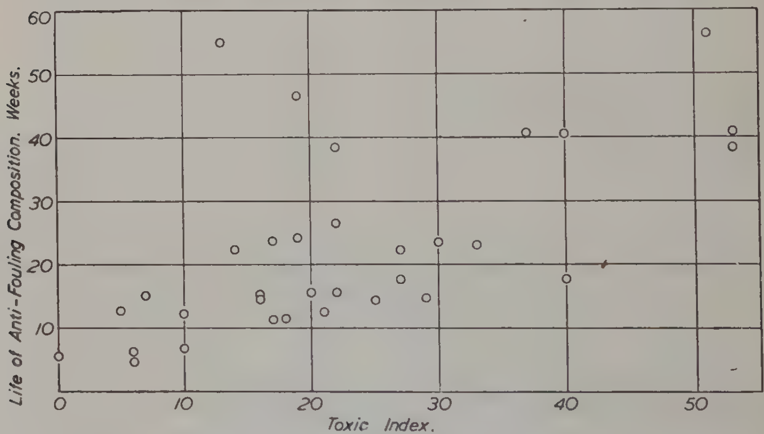


FIG. 3.—Series II. Caernarvon. Correlation of life of anti-fouling composition and toxic index (total toxin units).

medium in which they are bound. These factors are as yet imperfectly understood—indeed they constitute the *raison d'être* for a major part of the Sub-Committee's researches—but it is obvious that any comparison of proprietary anti-fouling compositions should take into consideration the marked variation in their toxin contents (*see* Table III.), coupled with the fact that all toxins are not equally effective. Analysis of the results at Caernarvon under discussion has shown that mercury is roughly twice as effective as copper in preventing fouling, whilst copper in turn is about three times as effective as arsenic in the form of arsenious oxide.[1]

[1] The results of later direct experimental investigations of the matter at Millport are reported in Section C, Part III.(*a*). These lead to the conclusion that arsenic is almost ineffective as an anti-fouling agent and consequently that a weighting factor of one-third is excessive.

Consequently the toxin contents of different compositions are best compared by expressing them in terms of a "toxic index," calculated by adding together twice the percentage (by weight) of mercury, the percentage of copper and one-third of the percentage of arsenious oxide. In Fig. 3 the lives of the 33 compositions are plotted against the toxic index calculated in this way. It will be noted, as showing the wide variation in commercial paints, that the latter range from 5 to 53.[1]

The points in Fig. 3 show considerable scatter. Several compositions give much better performance than would be expected from their toxic index. It is probable that at least four of these contain organic toxins in addition to the more usual compounds of mercury, copper and arsenic. Moreover, anti-fouling behaviour must depend not only on the percentage toxin content but also to some extent on the actual weight of toxins locked up in the paint film. An attempt to take this mass effect into consideration was made; the life of the anti-fouling composition was plotted against the product of the toxic index and the weight of wet paint applied. The correlation, although better than in Fig. 3, was still imperfect, no doubt because the important factor is not only the amount of toxins present but also the rate at which they are released at the exposed surface.

It may be concluded from Fig. 3 that, in the absence of compensating factors, such as the presence of organic toxins, it is improbable that an anti-fouling composition will have a life of 6 months under the experimental conditions at Caernarvon, unless its toxic index, calculated as above, exceeds 30.[2]

(3) *Effect of Protective Composition.*

Reference has already been made to the determining effect of the protective undercoats. It is essential not only that these shall adhere well to the steel base but also that the anti-fouling composition shall adhere equally well to them. In some painting schemes the anti-fouling coat was partly lost at an early stage; naturally, the high toxin content of the remainder did not prevent rapid fouling at the areas where the protective paint was exposed. Similarly, even if all the coats show good adhesion, rusting under the anti-fouling film will rapidly destroy its toxic properties. Many fouling organisms can settle on an almost microscopic area of non-toxic surface, *e.g.*, a rust spot, and will then continue to grow, even if this involves spreading over large areas of an adjacent highly

[1] The paint with zero toxic index was experimental.

[2] Although the effectiveness of mercury against weed fouling is approximately twice that of the same amount of copper, it is not correct to deduce that mercury can completely replace copper in an anti-fouling composition. With few exceptions, all the compositions tested contained both metals and the calculation of a toxic index in the above form is permissible.

toxic region. It would be difficult to over-emphasise the importance of a good protective system to the successful behaviour of an anti-fouling coat.

(4) *Effect of the Interval between the Application of the Anti-Fouling Coat and Immersion.*

It is undesirable that an anti-fouling composition should be appreciably affected by variations in the drying interval between its application and immersion, since the practical conditions of painting ships in dry-dock render wide variations in this interval inevitable. In order to study the effect of this variable, this interval was deliberately varied in the case of two painting schemes. Three sets of specimens painted with each were prepared with drying intervals of (*a*) 45 min., (*b*) 5 hr., the standard interval, and (*c*) 19½ hr.

The results of the test are given in Table XI. Those for scheme

TABLE XI.—*Effect of the Interval between the Application of the Anti-Fouling Coat and Immersion.*

Life expressed in weeks.[1]

Interval between the Anti-Fouling Coat and Immersion.	Scheme *A*.			Scheme *B*.		
	Repainted.	Pickled.	Mean.	Repainted.	Pickled.	Mean.
Hr. Min.						
0 45	23·3 f	40·8 f	32·0	12·1 rf	4·0 r	8·0
5 00	23·9 f	19·9 f	21·9	14·9 f	4·7 r	9·8
19 35	41·0 f	34·7 f	37·8	13·1 r	4·7 r	8·9

[1] f and r denote failure through fouling and rusting, respectively. The values are means for the front and back. rf denotes that the front failed through rusting and the back through fouling. In all other cases both surfaces failed through the same cause.

A, the better of the two, are erratic, but it can be said of scheme *B* that the marked variations in drying time have had no effect on the (poor) results obtained.

(g) *Protective Properties.*

As will be shown in the following discussion, values for the adhesion of the compositions after test, the loss of steel by corrosion and the depth of pitting at holidays were reasonably reproducible in the two series of tests. It may, therefore, be concluded that raft tests give a reliable indication of the protective properties of painting schemes.

(1) *Adhesion of Paint after Test.*

An analysis of the values for the amount of paint adhering to the specimens as cleaned after about 6 months' test at both stations is given in Table XII. In many cases the anti-fouling coat had

TABLE XII.—*Series I. and II. Adhesion of Painting Schemes after Test.*

Paint Adhering. %.	Number of Schemes.		
	Plymouth; 29 Weeks' Immersion. Pickled Specimens, 35 in number.	Caernarvon; 26 Weeks' Immersion.	
		Pickled Specimens, 40 in number.	Repainted Specimens, 35 in number.
100–91 . .	9	5	8
90–81 . .	8	6	12
80–71 . .	5	5	8
70–61 . .	9	5	3
60–51 . .	2	2	2
50–41 . .	1	9	1
40–31 . .	1	4	...
30–21 . .	...	...	1
20–11 . .	...	4	...
10–1 . .	...	...	...

flaked off locally, either during immersion or as a result of the final brushing, so that the figures represent the percentage areas over which at least the first protective coat was left intact but not necessarily all three coats. The wide differences in the adhesion of the painting schemes, from less than 20 to 100%, will be noted. In most cases good adhesion was associated with good protective properties, as judged by loss in weight, but a few of the paint films had softened during immersion and were readily removed by cleaning, despite the fact that little corrosion had occurred; probably these were near the end of their useful life.

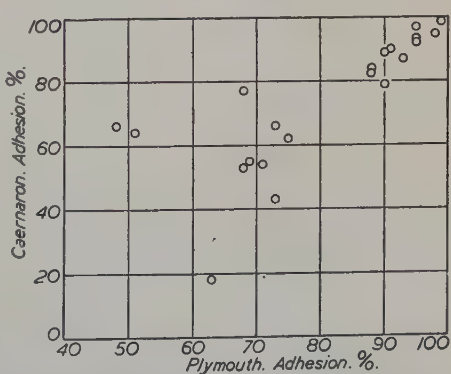


FIG. 4.—Series I. and II. Correlation of paint adhesion at Plymouth and Caernarvon.

The correlation between the Plymouth and

the Caernarvon results is best shown in diagrammatic form. Fig. 4 is a graph of the data for 21 schemes common to both series. The average adhesion was greater at Plymouth than at Caernarvon but the orders of merit are substantially the same.

The effect of old paint on adhesion was studied in some detail at Caernarvon. A grid dividing the surface into twelve equal areas was superposed on the old Plymouth specimens before they were repainted and the percentage of old paint adhering in each sub-

Table XIII.—*Series II. Caernarvon. Effect of Old Paint on the Adhesion of New Paint.*

Before Repainting.		After Repainting and Exposure.			
		Number of Areas with Intact Paint—			
Intact Paint. %.	Number of Areas.	100–90%.	89–60%.	59–30%.	29–0%.
100–90	99	67	30	1	1
89–60	435	210	200	20	5
59–30	305	84	180	36	5
29–0	73	9	29	24	11
Total	912	370	439	81	22

division was noted. Similar measurements were made after the conclusion of the Caernarvon tests. The two sets of observations are correlated in Table XIII. In only 62 cases out of 912 was a deterioration in adhesion recorded during the Caernarvon tests, and in the majority of cases, 536, an improvement occurred, thus confirming the conclusion that adhesion will generally improve as the paint film is built up by repainting.

Table XIV.—*Series I. and II. Proprietary Compositions. Corrosion of Basis Steel.*

Loss in Weight. Oz. per sq. ft.	Number of Painting Schemes.	
	Plymouth, 34 Specimens.[1] 29 Weeks' Immersion.	Caernarvon, 40 Specimens.[2] 26 Weeks' Immersion.
0·00–0·19	8	2
0·20–0·39	6	11
0·40–0·59	4	8
0·60–0·79	6	8
0·80–0·99	6	4
1·00–1·19	1	2
1·20–1·39	2	4
1·40–1·59	1	1

[1] One specimen was lost.
[2] The exposure of three specimens was continued beyond 26 weeks.

(2) *Loss in Weight on Exposure.*

The losses in weight of the pickled and painted specimens in both tests are given in Table XIV. These were determined after the remaining paint had been stripped and thus represent loss of steel.[1] The figures for Plymouth, after 29 weeks' immersion, ranged from nil to 1·48 oz. per sq. ft., and those for Caernarvon from 0·02 to 1·49 oz. per sq. ft. after 26 weeks' immersion. Comparable results for bare pickled steel are 1·78 and 1·39 oz. per sq. ft., respectively,

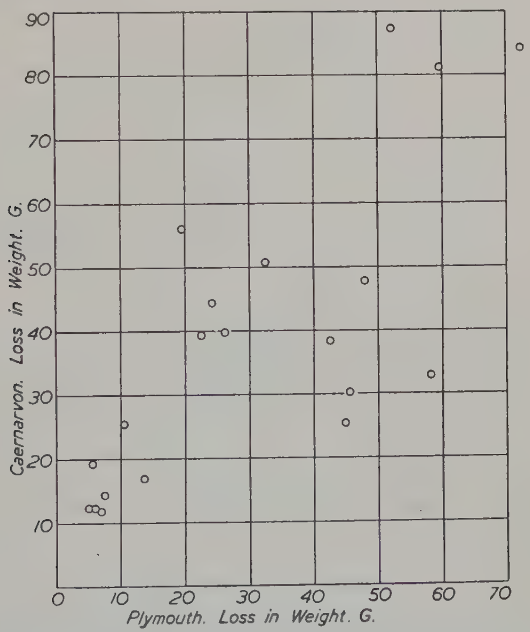


Fig. 5.—Series I. and II. Correlation of losses in weight at Plymouth and Caernarvon.

from which it may be concluded that the worst painting schemes gave little protection and broke down shortly after the tests were started. The contrast between good and bad protective paints is shown by the photographs of Plymouth specimens reproduced in Fig. 17.

The rates of corrosion, whether for painted or for bare specimens, were substantially the same at both stations. For bare steel, the equivalent annual corrosion rate is 2·93 oz. per sq. ft. at Plymouth and 2·86 oz. per sq. ft. at Caernarvon or, in terms of loss of thickness,

[1] The effect of the central holidays on the corrosion of these specimens would not be pronounced. The maximum correction for these would be 0·08 oz. per sq. ft.; in most cases it would be much less.

0·0045 and 0·0044 in. These rates are less than the normal rates of general corrosion in industrial atmospheres; for instance, at Sheffield rates of 4 oz. per sq. ft. or 0·006 in. per year have been observed in outdoor exposures.

Comparable values for the losses in weight of specimens painted with 20 schemes that were of substantially the same formulation in the two series are plotted in Fig. 5. The correlation between the Plymouth and Caernarvon results is good; the Spearman correlation coefficient works out at 0·760.

Attempts were made to correlate the protective properties of the compositions with the weight of each painting scheme. No correlation was found, although, as already discussed in Section B, Part II.(*b*)(2), there is evidence of the importance of the coating weight for any given paint. Clearly the effect of coating weight is masked by that of the wide variation in the medium and the pigmentation of the protective coatings. In addition, it would be better to base comparisons of different painting schemes on the total film thickness rather than on the total weight of paint. Unfortunately, the necessary data for making the calculations are not available for the tests under review.

(3) *Pitting at Holidays.*

The depth of penetration at the holidays left on the pickled specimens varied from 0·007 to 0·078 in. at Plymouth and from 0·012 to 0·066 in. at Caernarvon. These are mean values for both surfaces; the maximum recorded for any one holiday was 0·080 in. at Plymouth and 0·069 in. at Caernarvon. These high values, recorded after little more than 6 months' immersion, agree with practical experience of the dangerous concentration of attack at small unpainted areas on a ship's hull, particularly when the vessel is under way.

The results are summarised in Table XV. and, for the painting schemes common to both series, are correlated in Fig. 6. Again the correlation is good, the Spearman coefficient being 0·757. It may be concluded from the reproducibility of the results that the degree to which pitting is promoted at holidays is a characteristic property of the painting scheme.

Severe attack at the holidays was almost invariably associated with a high value for paint adhesion after test, but it does not follow that a scheme giving good adhesion will produce excessive pitting at holidays, since in several cases good adhesion was accompanied by moderate values for penetration. Conversely, a low value for the pitting does not necessarily indicate a good painting scheme, since bad protective coatings fail rapidly all over the surface, with the result that corrosion becomes general and is not concentrated at the holidays. It is a minor point but worthy of note that most of the compositions assessed as good protectives on the basis of the Plymouth tests had remained intact and protected the old holidays,

which were painted over when the specimens were re-exposed at Caernarvon, throughout the period of immersion there.

The scheme giving maximum penetration at Caernarvon, 0·066

TABLE XV.—*Pitting at Holidays.*

Depth of Pitting. In.	Number of Schemes.	
	Plymouth, 34 Specimens. 29 Weeks' Immersion.	Caernarvon, 40 Specimens. 26 Weeks' Immersion.
0·001–0·010 . . .	2	...
0·011–0·020 . . .	11	15
0·021–0·030 . . .	10	16
0·031–0·040 . . .	4	6
0·041–0·050 . . .	2	...
0·051–0·060 . . .	2	2
0·061–0·070 . . .	1	1
0·071–0·080 . . .	2	...

in., consisted of two coats of red-lead/oil paint followed by a finishing coat of a proprietary anti-fouling composition. It might be concluded from this that the use of red lead primers on the

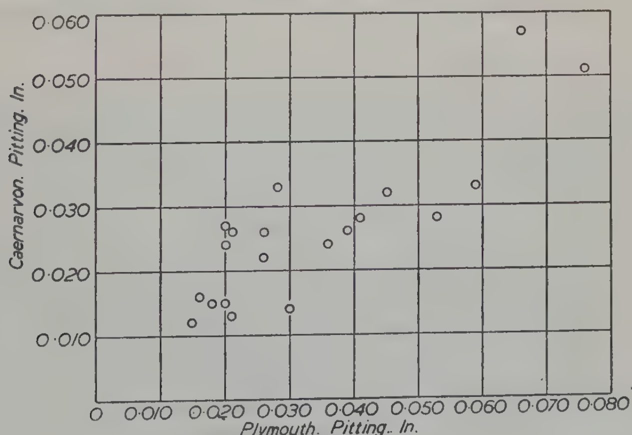


FIG. 6.—Series I. and II. Correlation of pitting at holidays at Plymouth and Caernarvon.

under-water parts of ships' hulls was dangerous and undesirable as being liable to promote serious pitting. This would be in line with practical experience in which heavy pitting of propeller shafts and similar parts wrapped in hessian soaked in red lead has sometimes

been observed. On the other hand, the experiments described in the next Part show that temporary coatings of red lead paint beneath the bottom painting scheme proper have materially improved the performance on new steel of an average proprietary painting scheme. Decision as to the merits or otherwise of red lead in bottom compositions must therefore be deferred until more experimental evidence is available.

(h) *Accelerated Tests with the Rotor Apparatus at the Chemical Research Laboratory.*

A special apparatus for accelerated corrosion tests under conditions of complete immersion has been designed and constructed at the Chemical Research Laboratory, Department of Scientific and Industrial Research, Teddington.[1] This provides for rapid motion of the test specimens through the corrosive solution, which at the speed employed (about 20 knots) is in a state of considerable turbulence and consequently of thorough aeration. The apparatus is well suited for conducting tests on painted steel surfaces moving rapidly through sea water, and the Chemical Research Laboratory kindly agreed to conduct parallel tests with this apparatus on the proprietary painting schemes included in the Plymouth and Caernarvon series of raft tests. Details of the apparatus and of the test results have not yet been published, but the author is indebted to the Chemical Research Laboratory for the following statement.

(1) *Experimental Details.*

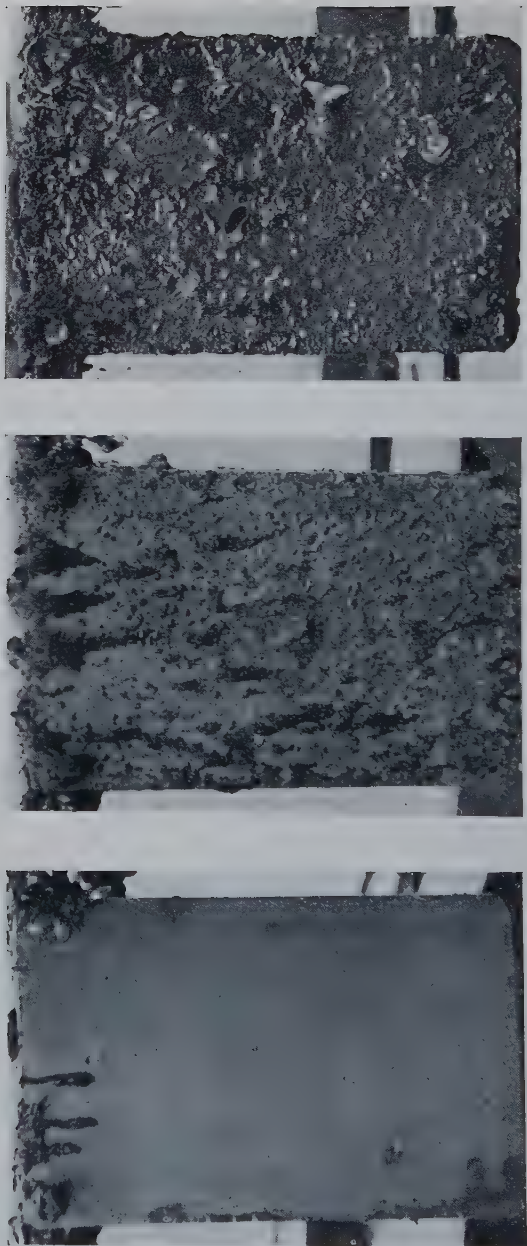
The tests on ships' bottom compositions are conducted as follows: The steel specimens are prepared for painting by pickling and wire-brushing; this leaves the metal with a bright, though roughened, surface, which can easily be reproduced and hence provides a convenient standard surface for use in comparing different paint systems. For painting, the specimens are held in slots in a vertical steel plate, with the surfaces of the specimens flush with that of the plate. In this way paint can be applied with a good sweep of the brush over a reasonable area, thus overcoming objections associated with the painting of small areas. The second (anti-corrosive) coat is applied after an interval of 27 hr., the anti-fouling after another 27 hr., and the specimens are immersed after a further 20 hr. The specimens are weighed (1) before painting, (2) after the application of the second anti-corrosive coat, and (3) after the anti-fouling coat, time being allowed for drying in each case.

In the tests under discussion, the specimens carried about the same (or a rather smaller) thickness of paint as the raft specimens. A preliminary experiment was duplicated with natural sea water and with a synthetic sea water containing all the principal ions in

[1] The apparatus is covered by a patent application in the names of G. D. Bengough, F. Wormwell, V. A. Yardley and T. J. Nurse.

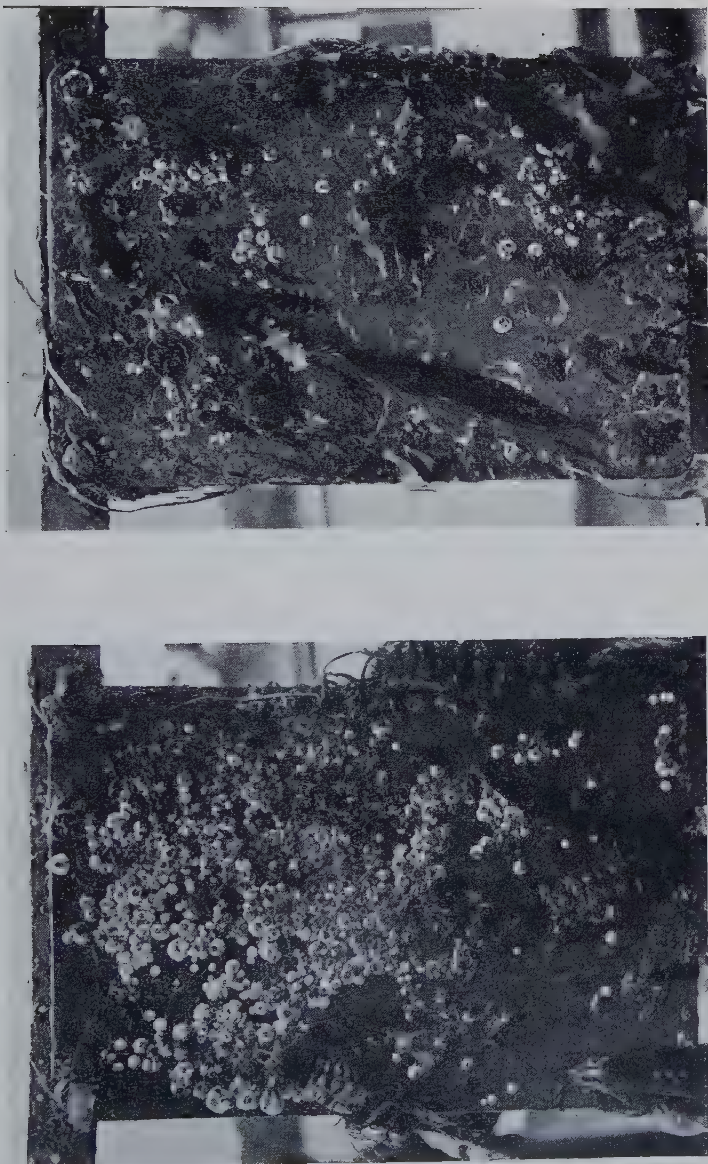
FIG. 13.—Exposure of the Specimens at Plymouth.

FIG. 14.—The Caernarvon Raft.



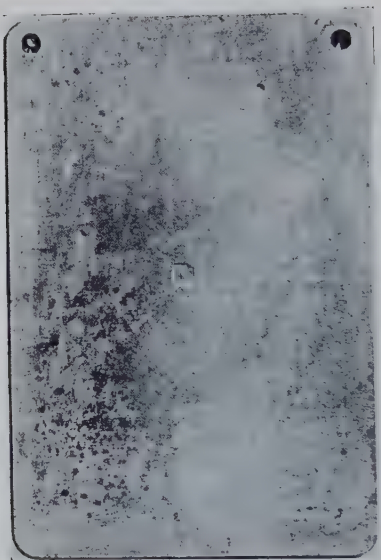
(a) Very good. (b) Moderate. (c) Bad.

FIG. 15.—Series I. Plymouth. Fouling of specimens after 29 weeks' exposure.

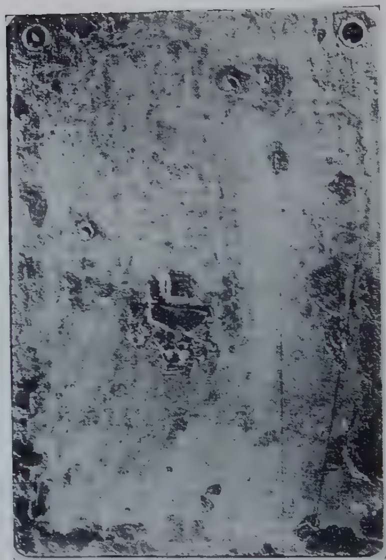


(a) (b)

FIG. 16.—Series II. Caernarvon. Fouling of specimens after 62 weeks' immersion.

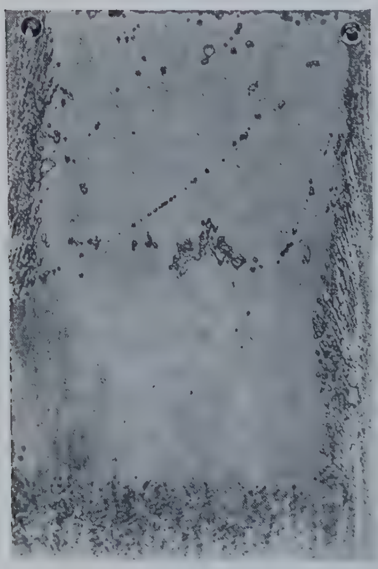


(*a*) Very good. Loss, 0·00 oz. per sq. ft. Pitting at holiday, 0·016 in.



(*b*) Bad. Loss, 1·48 oz. per sq. ft. Pitting at holiday, 0·024 in.

FIG. 17.—Series I. Plymouth. Good and bad protective paints.

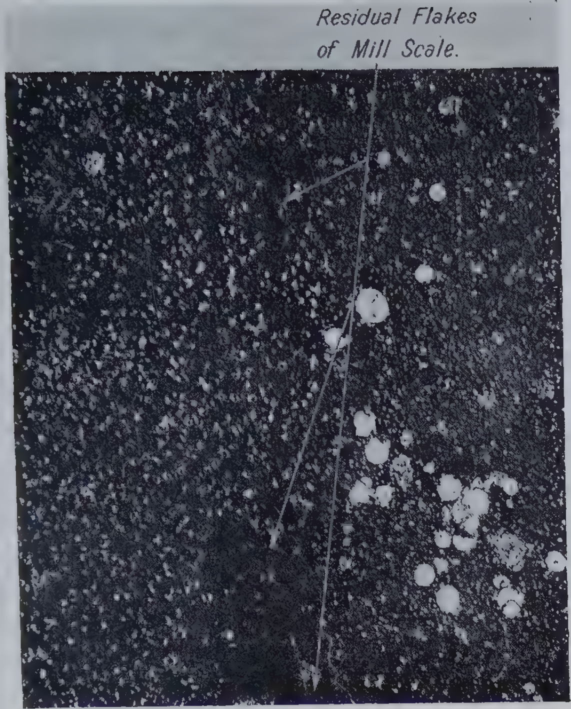


(*a*) Specimen after 35 days' weathering at Birmingham.

(*b*) Same specimen after receiving temporary protective coating followed by further 70 days' weathering at Caernarvon. Note breakdown of paint film at mill-scale/rust boundaries and at defects in mill scale.

FIG. 18.—Series IV. Caernarvon. Effect of rust and mill scale on protective paint.

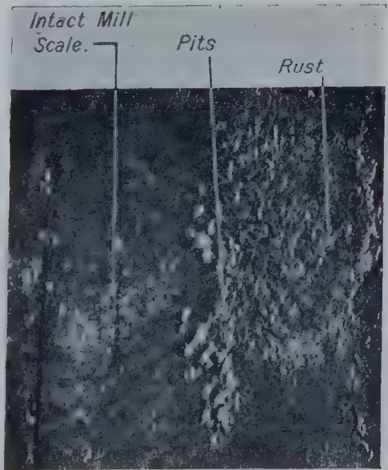
[*First Marine Corrosion Report.*



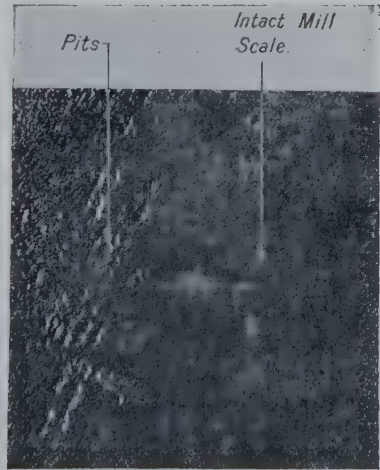
(*a*) Weathered for 105 days, then painted with scheme *D*.

(*b*) Weathered 35 days, bitumen-water emulsion temporary treatment, weathered 70 days, then scheme *D*. Note attack at mill-scale/rust boundary and absence of pin-head blistering over intact mill scale.

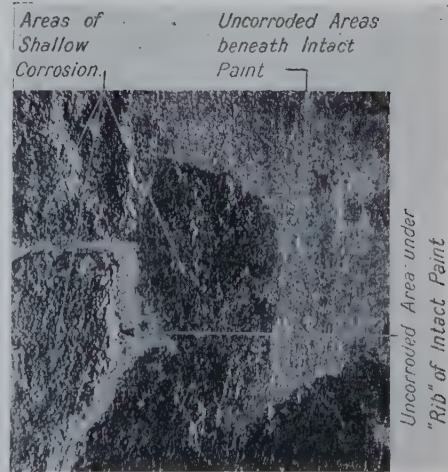
FIG. 19.—Series IV. Caernarvon. Pin-head blistering of compositions applied over a weathered steel surface; 25 weeks' immersion. Both specimens painted with scheme *D* and photographed after cleaning, *i.e.*, with the paint in position. (Photographed at natural size, reduced to two-thirds linear in reproduction.)



(a)



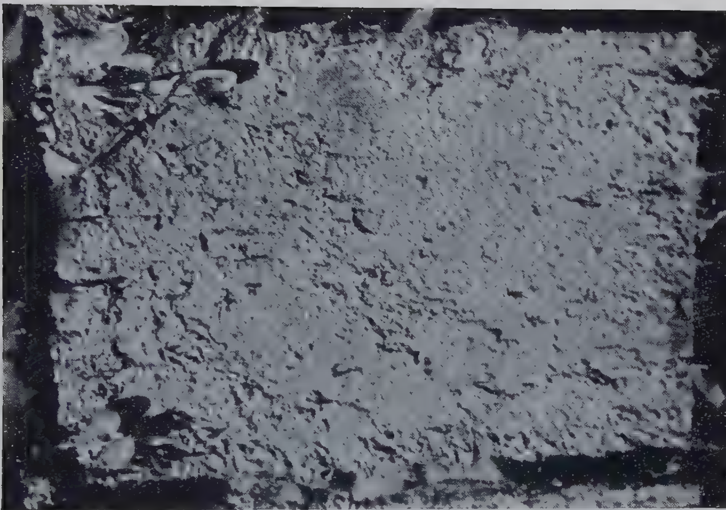
(b)

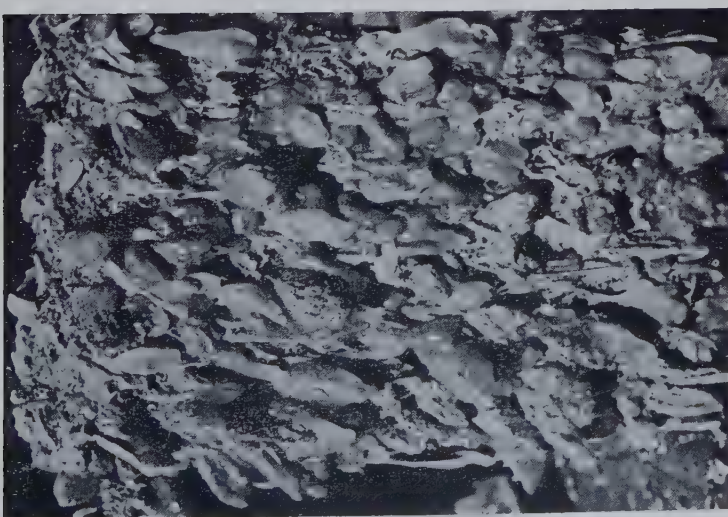


(c) Pickled, temporary coat of red iron oxide, then scheme *A*.

(*a*) and (*b*). Weathered 35 days, temporary red iron oxide coat, weathered 70 days, then scheme *A*. Note tendency of pits to follow cracked lines in mill scale produced by shearing.

FIG. 20.—Series IV. Caernarvon. Corrosion of specimens painted with scheme *A* after 25 weeks' immersion (the residual paint has been stripped). (Photographed at natural size, reduced to two-thirds linear in reproduction.)





(a) Aluminium, sprayed. (b) Zinc, hot-galvanised.

FIG. 21—Gosport. Fouling of aluminium- and zinc-coated steel; 12 months' immersion.

(a) Aluminium, sprayed.

(b) Zinc, sprayed.

FIG. 22.—Series III. Caernarvon. Fouling of naval compositions on aluminium- and zinc-coated steel; 54 weeks' exposure.

the concentrations as found in the natural water. Satisfactory agreement (in respect to the behaviour of the paint system under test) having been obtained, all the remaining tests were carried out in the synthetic solution.

(2) *Results.*

Evaluation of the results has been based on visual evidence supplemented by determinations of loss in weight of the basis metal. The ratings obtained by the two methods have, in the main, agreed well both with each other and with the ratings yielded by the Plymouth raft tests. The agreement with the latter is shown by the fact that of five schemes rated as very good by the C.R.L. test, three were rated as very good at Plymouth, one as good and one as moderate. At the other end of the scale sixteen schemes were rated as bad by the C.R.L. apparatus; in the Plymouth tests, thirteen of these were rated as bad and the remaining three as moderate.

In the Teddington laboratory experiments there are no means of assessing resistance to fouling, except in respect to the mechanical durability of the anti-fouling component under the conditions of the tests; the main criteria are, therefore, the "mechanical" behaviour of the paint coatings and the condition of the underlying metal in respect to corrosion.

It may be concluded from the good agreement between the results of the laboratory tests and the order of merit deduced from the Plymouth raft tests, that the C.R.L. apparatus affords a rapid and convenient method of testing paint systems intended for use on submerged metals. The absolute rate of breakdown of paints is much greater than in raft tests or (probably) on ships' plates in service. Thus, the percentage loss of paint in three weeks in the laboratory test is rather greater than that in twenty-nine weeks on the Plymouth raft.

(j) *Conclusions.*

Two main criticisms of these comparative tests on proprietary compositions have been voiced by individual paint manufacturers to whom the results of the tests on their own compositions have been communicated as a matter of courtesy.

(1) The paint films applied to the test specimens were much thinner than those used on actual ships. Some firms state that the spreading rates are three or four times greater than in their experience of painting ships' hulls.[1]

This is an inevitable result of the different methods of

[1] Service data obtained during tests on full-sized plates built into the bottom of H.M.S. *Basset* will be found on p. 205 of the Fifth Report of the Corrosion Committee (*Iron and Steel Institute*, 1938, *Special Report No.* 21). Here the total weight of wet paint in the three coats of composition applied before the first dry-docking was 1·32 oz. per sq. ft., equivalent to about 1 oz. per sq. ft. of dry paint (compare Table IV. of this Report).

application, coupled with the fact that the surface of a ship's hull will normally be rougher and more irregular than that of a small specimen. The effect of this difference in thickness may be reduced by the fact that it is common to most of the compositions tested.

(2) Raft tests do not reproduce the conditions of service. To this objection there can be no satisfactory answer until such time as it is possible to conduct service tests in parallel with raft tests and to correlate the two series of results.

With these possible limitations in mind, the main conclusions from this section of the work may be summarised thus :

(*a*) The results of raft tests are reproducible. There is good agreement between the Plymouth and Caernarvon series.

(*b*) Compositions generally have a longer life when applied over old paint than when applied to freshly pickled steel; in the former case failure occurs more frequently as a result of fouling but in the latter as a result of corrosion.

(*c*) The performance of relatively indifferent compositions improves as a paint film is built up on the steel by repainting. A distinction should therefore be made between compositions applied in the early stages of a ship's history and those used for maintenance after the vessel has been in commission for a number of years.

(*d*) The behaviour of an anti-fouling composition is indissolubly connected with that of the protective paint beneath it and can only be fully satisfactory when the latter prevents any rusting of the steel. It follows that comparative tests of anti-fouling compositions as such should be conducted over a protective system satisfying this condition.

(*e*) To prevent gross fouling under the static experimental conditions in home waters for six months in summer, considerable concentrations of toxins are required in the anti-fouling composition. These may be roughly assessed as 15% by weight of mercury or 30% by weight of copper or an equivalent combination of both.

(*f*) Marked pitting may occur at unpainted areas (holidays) left in an otherwise sound coat of composition. Red lead in linseed oil has the most pronounced pitting effect of any primer investigated.

(*g*) It is desirable to pay more attention to the formulation of ships' bottom compositions with a view to obtaining the optimum consistency for application, paying due regard to practical working conditions.

(*h*) Whilst the possible limitations of the results of the present raft tests as a basis of selection for anti-fouling compositions for use on seasoned vessels are recognised, it is considered that they give a good indication of the relative merits of protective compositions.

(*j*) Good agreement as regards the protective properties of the various painting schemes was observed between the results of accelerated laboratory tests conducted in the rotor apparatus at the Chemical Research Laboratory and those of the raft tests.

PART IV.—SERIES IV.[1] EFFECT OF SURFACE CONDITION.

(a) *Experimental Details.*

With the conclusion of test series II. at Caernarvon, the work of the Sub-Committee entered on a new phase. In subsequent series the aim has been not so much to compare rival proprietary compositions as to build up a body of scientific evidence on which improved ships' bottom compositions could be formulated, and the effect of various factors incidental to the painting process, such as the preparation of the steel surface for painting, could be correctly appraised.

The first of these tests, series IV., was designed to investigate the effect of variations in the surface treatment of the steel before painting.

It may be postulated that the ideal method of dealing with new ships' plates would be to remove the mill scale and any rust by pickling or other means after the completion of fabrication and to apply a complete priming coat to them under good conditions before they left the shop. Unfortunately, there are practical difficulties which conflict with this ideal. For instance, it would be undesirable to paint the edges, since trouble might arise in cases where welding was used for assembly and the presence of paint would interfere with the conduct of the water-tightness test.[2]

Attention was paid to these and similar points when drawing up the experimental programme. For example, it was envisaged that, although the plates might be pickled in practice, some time might elapse before they could be painted. Painting could, however, be carried out in position as soon as any particular section of the hull had passed the water-tightness test. A single coat of paint might then be applied to afford temporary protection until the final painting of the hull as a whole. Consequently, tests on various temporary protectives such as red lead, red iron oxide paint or mineral oil, as used in H.M. Navy, have been included. Similar experiments were made on plates exposed to the weather for different periods, with or without temporary protective treatments, and on plates coated with red lead or with red iron oxide paint at the steelworks within a short time of rolling.

After the various preliminary treatments, the specimens were given three coats of composition, two protective and one anti-fouling, and were then immersed in the sea. The final painting scheme was varied, but one scheme was applied to nearly half the total number of specimens. This scheme and four others need alone be considered here.

[1] Series III. is considered in Section B, Part IX.(*b*).

[2] The possibility of devising a paint that would not interfere with welding should not be ignored.

Table XVI.—*Series IV. Tests on*

Surface Condition.			Weight of Dry Paint. Oz. per sq. ft.									
			A.		*B.*		*C.*		*D.*		*E.*	
Bm.	Temporary Treatment.	Cn.	t.	f.	t.	f.	t.	f.	t.	f.	t.	f.
Nil	Red lead at mill	105	...	0·50	...	...	...	...	...	...	...	...
,,	Red iron oxide at mill	,,	...	0·49	...	...	...	...	...	...	...	...
,,	None	,,	...	0·49	...	1·03	...	0·67	...	0·42	...	1·80
p	None	105	...	0·49	...	0·94	...	0·71	...	...	...	...
14	Red iron oxide	91	0·14	0·46	...	...	...	...	...	...	...	...
14p21	Boiled oil	70	0·05	0·53	...	...	...	...	...	...	...	...
,,	Mineral oil	,,	0·05	0·49	...	...	...	...	...	...	...	...
,,	First protective	,,	0·08	0·50	0·40	1·12	0·07	0·71	...	...	0·09	1·83
,,	Red lead	,,	0·30	0·45	...	...	...	...	...	...	...	...
,,	Red iron oxide	,,	0·15	0·50	...	...	0·13	0·66	...	...	...	...
,,	Bitumen-water emulsion	,,	...	...	...	...	...	...	0·12	0·42	...	...
35	Mineral oil	70	0·04	0·51	...	...	...	...	...	...	...	...
,,	First protective	,,	0·09	0·42	0·44	1·02	0·09	0·64	...	...	0·08	1·77
,,	Red lead	,,	0·34	0·51	...	...	...	...	...	...	...	...
,,	Red iron oxide	,,	0·16	0·47	...	...	...	...	...	...	...	...
,,	Bitumen-water emulsion	,,	...	...	...	...	...	...	0·12	0·42	...	...
35p	None	70	...	0·50	...	...	...	0·72	...	...	...	1·81
,,	Red lead	,,	0·31	0·48	...	...	...	...	...	...	...	...
,,	Red iron oxide	,,	0·18	0·46	...	...	...	...	...	...	...	...
70	Red iron oxide	35	0·16	0·51	...	...	...	...	...	...	...	...
70p	None	35	...	0·46	...	...	...	0·70	...	...	...	...
91p	None	14	...	0·56	...	...	...	0·72	...	...	...	...
Nil, p	None	Nil	...	0·48	...	...	...	0·67	...	...	...	2·03
,,	Red lead	,,	0·32	0·52	...	...	...	...	...	...	...	...
,,	Red iron oxide	,,	0·17	0·46	...	...	...	...	...	...	...	...
Nil	Red lead at mill	Nil	...	0·45	...	...	...	...	...	...	...	...
,,	Red iron oxide at mill	,,	...	0·46	...	...	...	...	...	...	...	...

Key to

Surface Condition.	Weight of Dry Paint.
Bm = Birmingham. p = pickled in dilute hydrochloric acid. Cn = Caernarvon. The figures refer to days' exposure. *Example*: "14p21, boiled oil, 70" denotes "specimen exposed for 14 days at Birmingham, pickled, re-exposed for 21 days at Birmingham, coated with boiled oil, exposed for 70 days at Caernarvon.	*A, B, C, D, E* = different painting schemes. *D* incorporated bitumen in the protective coats. *E* had a wax anti-fouling which was applied hot. t = temporary coat. f = final painting scheme, total for two protective coats and one anti-fouling coat.

Details of the tests are given in Table XVI. They were begun in January, 1942, and the Table gives results for periods of 6 and 8 months' immersion, terminating in July and September, 1942, respectively.

(b) *Effect of Weathering.*

The changes in weight of the as-rolled or pickled specimens as a

the Effect of Surface Condition.

Grading after 6 Months' Immersion.										Grading after 8 Months' Immersion.									
A.		*B.*		*C.*		*D.*		*E.*		*A.*		*B.*		*C.*		*D.*		*E.*	
F.	P.	F.	P.	F.	P.	F.	P.	F.	P.	F.	P.	F.	P.	F.	P.	F.	P.	F.	P.
M M b	G b b	... ... VG	... ... M	... ... VG	... ... M	... ... b	... ... b	... ... b	... ... VG	M ... b	G ... b	... ... G	... ... M	... ... G	... ... M	... ...	... ...	... ... b	... ... VG
M	M	VG	G	VG	b	...	...	...	...	b	M	G	M	VG	b	...	...	...	...
b	b	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
b M M G b ...	b b b M b ...	... ... VG	... ... G	... ... VG ... VG ...	... ... G ... G ...	... ... M	... ... b	... ... b	... ... VG	... b b M	... b b M	... ... G	... ... M	... ... VG ... G ...	... ... G ... G ...	... ...	... ...	... ... b	... ... VG ... ...
M b G b ...	M b G b ...	... VG	... G	... VG	... G	... ... M	... ... b	... b	... VG	b ... M	b ... G	... G	... G	... VG	... G	... ...	... ...	... b	... VG ... ...
M M b	M G b	... ...	... ...	VG	M	... ...	... ...	b	VG	b b ...	b M ...	... ...	... ...	G	b	... ...	... ...	b	VG ... ...
b	b	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
b	b	...	...	VG	G	...	...	...	...	...	...	...	...	VG	G	...	...	...	...
M	M	...	...	VG	G	...	...	...	...	b	b	...	...	VG	G	...	...	...	...
b M b	b G b	... ...	... ...	VG	VG	... ...	... ...	b	VG	... b ...	... G ...	... ...	... ...	G	VG	... ...	... ...	b	VG ... ...
M b	G b	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	M ...	G ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...

TABLE.

Gradings.

F = fouling.
P = protection.
VG = very good.
G = good.
M = moderate.
b = bad.
Where gradings are underlined, the specimen was removed after this inspection.

result of the preliminary weathering, &c., are given in Table XVII. It should be noted that the specimens were cut from ships' plate of ordinary steel, $\frac{1}{4}$ in. thick.

(1) *As-Rolled Specimens.*

It will be seen from Table XVII. that the percentage of mill

scale removed by weathering increased progressively with increasing duration of exposure, and had reached 87% after 105 days' weathering at Caernarvon. It is inadvisable to make a general deduction from this as to the time necessary to descale a ship's plate completely by weathering, since, apart from incidental variations in the conditions of exposure, including the season of the year, this will depend on the thickness of the plate and the speed of the mill in which it was rolled, both of which affect the constitution and thus the resistance

TABLE XVII.—*Effect of Weathering on Uncoated Steel.*

Weathering.		Total Specimens.[2]	Descaling. %.	Change in Weight. Oz. per sq. ft.[1]				
Days.	Place.			Gain on Exposure.	Loss on Wire-Brushing.	Net Loss.	Rust Left after Cleaning.	Loss on Pickling.
	Specimens Exposed in the As-Rolled Condition.							
0	...	20	...	...	...	...	...	0·54 [3]
14	Birmingham	22	18	0·01	0·02	0·02	0·09	0·53
35	,,	30	27	0·03	0·10	0·08	0·10	0·48
70	,,	6	36	0·07	0·21	0·14	0·16	0·62
91	,,	4	46	0·15	0·33	0·17	0·31	0·71
105	Caernarvon	15	87	0·12	0·56	0·44	0·21	...
	Specimens Exposed after Pickling.							
14	Caernarvon	4	...	0·10	0·12	0·02	0·13	...
21	Birmingham	20	...	0·09	0·13	0·03	0·10	...
35	Caernarvon	4	...	0·14	0·22	0·07	0·14	...
70	,,	7	...	0·24	0·37	0·13	0·23	...
105	,,	6	...	0·30	0·37	0·07	0·38	...

[1] Apparent errors of 0·01 in some of the differences shown are due to the fact that the figures have been converted from gramme per specimen to ounce per square foot.

[2] In some cases only part of the total was pickled after exposure.

[3] Range 0·46–0·60.

of the mill scale to weathering. It is probable, however, that on the general run of ships' plates descaling would seldom be completed within six months and that much longer might often prove necessary to make sure of complete scale removal.

(2) *Pickled Specimens.*

The loss in weight on pickling of as-rolled specimens that had been subjected to no preliminary exposure other than that unavoidably incurred in transit from the steelworks averaged 0·54 oz. per sq. ft. (limits 0·46–0·60 oz. per sq. ft.). Pickling was carried out in cold 5% (by volume) hydrochloric acid according to the standard Admiralty procedure. Under normal circumstances there is little loss of metal from the plates in this process, so that the

figure of 0·54 oz. per sq. ft. may be taken as the approximate weight of rolling scale on the specimens. It is clear from Table XVII. that the effect of long periods (*i.e.*, 70 or 91 days) of exposure to weathering before the specimens are pickled results in an appreciable increase in the loss in weight on pickling. This increase is largely due to the formation of rust. This has the additional disadvantage that, since rust is more difficult to remove than mill scale, the pickling time is unduly prolonged; moreover, the final surface is not so good. The practical conclusion to be drawn is that plates should be pickled as soon as possible after they have been rolled. It is bad practice to allow plates to become heavily rusted before pickling them.

The results given in Table XVII. show that the pickled specimens gained weight on exposure for all periods up to the maximum of 105 days; this is due to the formation of rust. Rust is generally found to contain about 60% of iron; consequently, it may be assumed that a gain in weight of 1 oz. on exposure represents the formation of 2·5 oz. of rust, resulting from the corrosion of 1·5 oz. of iron. These are minimum values, because the calculation assumes that there is no loss of rust from the surface either by solution in rain water or by mechanical means. On this basis, the gain in weight (per sq. ft.) of 0·30 oz. after 105 days at Caernarvon indicates the presence on the surface of the specimens of 0·75 oz. or more of rust; since only 0·37 oz. was removed by wire-brushing, at least 0·38 oz. of rust must have remained on the surface of these specimens as painted. The results of similar calculations, recorded in Table XVII., show that, as would be expected, the amount of rust that is not removed by wire-brushing increases with the duration of exposure. It may be noted that in other experiments the weight of rust left after wire-brushing specimens that had been exposed out of doors for a year was approximately 1·0 oz. per sq. ft.

The wire-brushing was thorough and was carried out at a rate of approximately 12 sq. ft. per hr., the average time spent on each specimen, with a total area of 2·2 sq. ft., being from 10 to 12 min. At this rate of wire-brushing, it seems that, judging from visual appearance, practically all the rust can be removed from pickled steel that has not been exposed to the weather for longer periods than about four weeks. The complete removal of the rust is, however, illusory, as is shown both by the data given above and by the fact that in the case of temporary treatments applied to specimens wire-brushed after weathering for 14 days after pickling, the tiny pin-point blisters associated with subcutaneous rust were discernible in the paint films after these had been exposed for a further 70 days at Caernarvon.

The practical conclusion is that the first protective treatment of ships' plates, whether temporary or permanent, should be applied as soon as possible after the plates have been pickled and, except under unavoidable circumstances, within two or three weeks of this.

Values for the weights of rust left on as-rolled specimens after

weathering are also shown in Table XVII. In this case the calculation is complicated by the loss in weight due to removal of the mill scale itself, and the results are more approximate; in all probability the figures given are too low. In fact, in the atmospheric exposure tests of the Main Committee it has generally been found that complete mill scale removal by natural weathering has the effect of leaving a quantity of rust on the surface after thorough wire-brushing that is approximately equal in weight to the original weight of mill scale.

(c) *Effect of Temporary Protective Treatments.*

Temporary protective treatments were applied at an intermediate stage of the weathering process to two sets of specimens, as shown in Table XVIII. In one case the specimens were weathered for 14

TABLE XVIII.—*Effect of Temporary Protective Treatments on Resistance to Weathering.*

Temporary Treatment.	Spreading Rate. Sq. ft. per gal.	Treatment before Coating.			
		Weathered 14 Days, Pickled Hydrochloric Acid, Weathered 21 Days, Wire-Brushed.		Weathered 35 Days, Wire-Brushed.	
		Coating Weight. Oz. per sq. ft.	Loss in Weight. Oz. per sq. ft.	Coating Weight. Oz. per sq. ft.	Loss in Weight. Oz. per sq. ft.
Boiled linseed oil	3000	0·05	—[2]	Not tested	...
Mineral oil	3000	0·05	0·20	0·04	0·08
Red lead	1500	0·30	0·01	0·34	0·01
Red iron oxide	1800	0·14	−0·01	0·16	0·01
Bitumen-water emulsion	...[1]	0·12	—[2]	0·12	0·02
First protective: *A*	...[1]	0·08	—[2]	0·09	0·04
B	...[1]	0·40	—[2]	0·44	—[2]
C	...[1]	0·07	—[2]	0·09	—[2]
E	...[1]	0·09	—[2]	0·08	0·02

[1] Not determined, but between 1000 and 2000 sq. ft. per gal.
[2] Less than 0·01.

days at Birmingham, pickled in cold hydrochloric acid and again exposed out of doors for 21 days before they were thoroughly wire-brushed and given a single coat of the temporary treatment. In the other case the specimens were weathered for 35 days at Birmingham under the same conditions before being wire-brushed and coated in a similar manner. After receiving the temporary treatment, all the specimens were sent to Caernarvon and exposed to the weather there for 70 days. The losses in weight recorded in Table XVIII. are the differences between the weights of the freshly-

coated specimens and the corresponding weights when they had been wire-brushed after the 70 days' exposure at Caernarvon, *i.e.*, in most cases they represent loss of coating rather than loss of steel. A change in weight of 0·01 oz. per sq. ft. is roughly the smallest that can be detected with certainty, and a dash in the Table indicates that the observed value was less than this.

The oil coatings were rubbed on by means of rags at the rate of about 3000 sq. ft. per gal. and the red lead and red iron oxide paints were suitably thinned before use. First protective *B* was also thinned for use as a temporary coat, but the other first protectives and the bitumen-water emulsion were used as they stood without dilution.

All the temporary treatments, except mineral oil, protected the steel adequately over the 70 days' exposure to the weather. It is noteworthy that with most of the treatments the loss in weight of the non-pickled specimens, weathered for 35 days before treatment, although small, was greater than that of the specimens that were pickled after 14 days' exposure. This is due to the fact that 73% of the mill scale was still adhering to the former at the time of painting, which resulted in local breakdown of the paint film at the boundaries of the intact mill scale left in the centre during the further exposure at Caernarvon. This is illustrated by Fig. 18.

The mineral oil gave bad results and the specimens that had received this treatment were indistinguishable after weathering from the uncoated specimens. For specimens that had received an intermediate pickling, for instance, the loss in weight after 70 days' exposure at Caernarvon was 0·20 oz. per sq. ft. as compared with 0·24 oz. per sq. ft. for non-coated specimens. No comparable set of non-coated specimens carrying mill scale was tested, but the mineral oil probably had some effect in retarding descaling, since at the final inspection only 11% of the mill scale had been removed from the specimens, as compared with 87% for uncoated specimens exposed for the full period of 105 days. The loss of this mill scale accounts for the fact that the specimen that had been weathered continuously for 35 days before oiling lost less weight on further exposure than the one that had received an intermediate pickling after 14 days' exposure.

It will be seen that boiled linseed oil, applied in the same manner and at the same spreading rate, gave much better results than mineral oil. It may be concluded that, for use as a temporary protection against atmospheric rusting, boiled linseed oil is to be preferred to mineral oil. The results show that the former, applied at the rate of 3000 sq. ft. per gal., will give good protection in the open for 2–3 months under normal circumstances. It is too early to decide between the merits of the various paints applied, but it is encouraging to note that the bitumen-water emulsion, which is easy to apply, gave results comparable with those for the other temporary protectives. The question of the value of these and

other temporary treatments for ships' plates to be coated subsequently with bottom compositions and immersed in sea water is another matter and will be discussed later.

(d) *Results to Date.*

The coating on some of the specimens failed rapidly when immersed; moreover, for various reasons gradings at successive inspections fluctuated considerably, rendering it difficult to assess the life of coating in individual cases. Comparisons of the different treatments have therefore been made by means of index figures computed thus :

Fouling.—The aggregate for all inspections to date[1] of all fouling gradings other than slime for the fronts and backs of both duplicate specimens, *i.e.*, for four surfaces in all.

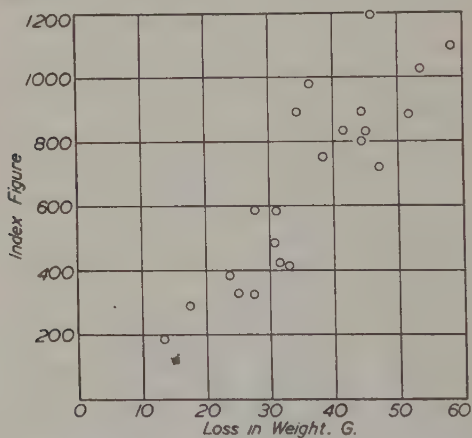


FIG. 7.—Series IV. Caernarvon. Correlation of index figure (protection) and loss in weight.

Protection.—The aggregate, as above, for the percentage of blistering, twice the percentage of flaking and four times the percentage of rusting. The weighting factors, one, two, four, are purely arbitrary, but, as will be seen from Fig. 7, their use is justified by the good correlation of the index figures with the observed losses in weight of the specimens after immersion.

On the basis of these index figures, the various combinations of surface treatment and final coating have been graded as "Very good," "Good," "Moderate" and "Bad," as shown in Table XVI. In the case of the 6 months' results, the dividing line between

[1] Six in number at 6 months, seven at 8 months.

moderate and bad is the average index figure for all the pairs. The top fifth of the range above this constitutes the very-good class, the second and third fifths are good and the remaining (bottom) part of the range is moderate. Most of the bad specimens had failed at 6 months and were removed then. The gradings at 8 months are, so far as possible, on the same absolute scale as those at 6 months.

Most of the specimens painted with schemes *B*, *C* and *E* were in good condition, as regards absence of rusting, after 8 months' immersion, and it would be premature to discuss the results of the tests on these, since any differences observed may be within the experimental error. Scheme *D* was applied to three pairs of specimens only. Consequently, interim discussion of the results will be based mainly on those obtained for specimens coated with scheme *A*. This is a proprietary scheme which, on the basis of the results obtained at Plymouth and Caernarvon (series I. and II.), would be classed as moderate, *i.e.*, above the general average (*see* Table VII.).

Three main conclusions emerge :

(1) Temporary treatments of red lead paint have led to marked improvement in performance in the underwater tests, irrespective of the stage in the history of the specimens at which they were applied. In fact, the improvement is such that the best of these specimens are graded as good after 8 months' immersion and equal in merit to all but the best specimens painted with schemes *B* and *C*. The latter are proprietary compositions in the good or very-good class.

Reference has been made (Part III.(*g*)(3)) to the tendency for red lead to promote pitting at holidays on a steel surface. It is not certain that this would be so pronounced in the case of a thinned coating such as that used in these tests for temporary protection, or, *a fortiori*, in that of a paint specially formulated for use under bottom compositions.

(2) In contrast to this, temporary treatments of red iron oxide paint, of boiled oil and, strangely enough, of the first protective coat of scheme *A* itself have proved injurious and yielded worse results than those obtained on weathered steel with no temporary treatment at all. The detrimental effect of red iron oxide paint was particularly marked. Red iron oxide paints as a class dry slowly and give a softer film than red lead paints, so that it might be possible to obtain an improved result by formulating a special quick-drying red iron oxide paint for the purpose. It is probable, however, that the main cause of the difference in the behaviour of red lead and of red iron oxide paints is the strongly inhibitive character of the former, which restrains rusting.

Specimens coated with mineral oil ranked slightly higher in the order of merit than those coated with boiled oil, but this is purely a negative virtue, since both were inferior to weathered specimens with no temporary treatment.

(3) Better results were obtained on steel that had been exposed to the weather for 105 days after pickling, followed by wire-brushing before painting, than on freshly pickled steel; as-rolled specimens exposed for 105 days also gave better results than pickled but unweathered ones. It follows that with scheme *A* the development of rust on a pickled surface has not had the injurious effect that would have been expected in the case of paint applied for protection against atmospheric corrosion. It would seem that here the rust improves adhesion by acting as a key for the paint or, alternatively, that there is some incompatibility between this paint and a freshly pickled steel surface.

This result may not be a general one. With scheme *C*, a better protective paint, the best specimens after 8 months are those painted on a freshly pickled surface. Specimens painted over a rusted surface are inferior. The difference lies in the development of minute blisters on the latter; these affect the grading, but may not prove to be of such importance as they seem. This type of blistering, which is also observed in paint films applied over rusty steel exposed to the atmosphere, is illustrated in Fig. 19. In this case the paint on the specimens is scheme *D*.

It is interesting, too, that temporary treatments of red iron oxide paint have had no adverse effect so far on specimens coated with scheme *C*.

(e) *Loss in Weight and Pitting on Exposure.*

Twelve pairs of specimens painted with scheme *A* were removed in July, 1942, after 25 weeks' exposure. Their losses in weight, after stripping any remaining paint, are given in Table XIX. The

TABLE XIX.—*Series IV. Caernarvon. Loss in Weight, Paint Adhesion and Pitting after* 25 *Weeks' Immersion* (*Painting Scheme* A).

Surface Condition.[1]			Loss in Weight.[2] Oz. per sq. ft.	Paint Adhering.[2] %.	Deepest Pits.[3] Thousandths of an Inch.			
Bm.	Temporary Treatment.	Cn.						
70p	None	35	0·30	29	—	—	52	—
35	First protective	70	0·39	11	—	21	—	—
70	Red iron oxide	35	0·40	36	34	32	24	28
14p21	Boiled oil	70	0·42	7	—	—	—	46
35	Red iron oxide	70	0·50	10	32	22	22	—
14p21	Red iron oxide	70	0·52	11	15	—	—	—
p	None	Nil	0·60	4	—	—	—	—
35p	Red iron oxide	70	0·65	5	—	—	—	—
p	Red iron oxide	Nil	0·70	3	—	—	—	—
Nil	Red iron oxide at mill	105	0·73	8	—	—	—	—
14	Red iron oxide	91	0·77	6	—	—	—	—
Nil	Red iron oxide at mill	Nil	0·80	6	—	28	—	—

[1] See key to Table XVI. [2] Mean values for two specimens.
[3] Value for each of four surfaces. A dash indicates less than 0·015 in.

mean values ranged from 0·30 to 0·80 oz. per sq. ft., with an average of 0·57 oz. per sq. ft.; the maximum and minimum values for individual specimens were 0·21 and 0·93 oz. per sq. ft., respectively. It may be noted that in series II. (proprietary compositions) the limits of the loss in weight for the moderate class were 0·35 to 0·58 oz. per sq. ft. after 26 weeks' immersion at Caernarvon.

With few exceptions, the amount of paint left adhering to the specimens after the usual final cleaning in running water did not exceed 10%, as shown in Table XIX. The figures confirm the poor adhesion of scheme *A* to freshly pickled steel and that this adhesion is improved by a period of exposure to the weather before painting. The detrimental effect of temporary treatment with red iron oxide paint or boiled oil is also evident, particularly when this Table is studied in conjunction with Table XVI.

It will be recalled (Table XVII.) that the preliminary weathering of the as-rolled specimens for periods of 35 or 70 days did not suffice to remove all the mill scale, so that in several cases the temporary treatments were applied to specimens on which the mill scale had been replaced by rust in a border of varying width (up to 1 in.) round the edges but was more or less intact on the centre. The final examination of the specimens after stripping the paint showed that in all cases where mill scale had been left on the steel beneath the paint, marked pitting had developed at the boundaries between intact scale and the rusted steel; moreover, on some specimens the mill scale was crumbling and flaking below the residual paint film.

Figures for the depth of pitting are given in Table XIX. For specimens painted over weathered mill scale they ranged up to a depth of 0·034 in. This figure was exceeded at two isolated pits on specimens that had been descaled by pickling, but otherwise sharp pitting was not marked on pickled surfaces. Here the corrosion was of a different type and took the form of local attack over comparatively large areas, which were corroded uniformly to a shallow depth. Inspection of the specimens renders it probable that these are areas from which the paint had flaked away prematurely, leading to local concentration of the attack similar to that observed at holidays. The photographs reproduced in Fig. 20 are characteristic of the pitting of specimens carrying rolling-mill scale and of the local attack on pickled specimens.

It may be concluded from these observations that mill scale should be entirely removed from ships' plates before they receive their initial coat of paint. Since it is improbable that this can be accomplished on the large number of plates required for a single hull by the normal processes of weathering in the shipyard or on the stocks, more attention should be devoted in shipping circles to the possibility of descaling plates by the only reliable methods, pickling or shot-blasting. Obviously it cannot be claimed that pickling alone is an infallible solution of the problem. Its use will have to be bound up with that of properly formulated priming paints giving

good adhesion and protection to the bare steel surface. On the other hand, it is clear that complete descaling before painting is the only safe method of eliminating the danger of pitting as a result of electrochemical action, which will persist so long as any mill scale is allowed to remain on the steel.

Part V.—Series V. New-Type Protective Paints (Dr. U. R. Evans).

Emphasis is always laid, and rightly so, on the necessity that all protective coatings for iron or steel should be applied under good conditions (of temperature, humidity, &c.) if the best results are to be obtained. In practice, however, these ideal conditions cannot always be realised, particularly where maintenance painting is concerned; for instance, the painting of a ship in dry-dock cannot be held up for bad weather. Dr. U. R. Evans and his collaborators at Cambridge have, therefore, been investigating another fundamental solution of the problem and have been endeavouring to establish formulations for paints that can be applied under adverse conditions—say, to a rusty, wet steel surface—and yet give good results. Into the nature of these paints it would not, at the moment, be seemly to go, but it may be said that some of them are on an inorganic base and differ fundamentally from the type of composition normally used at present, whilst others, developed by Dr. J. E. O. Mayne, are based on organic vehicles.

As preliminary tests on small specimens had yielded good results in the Cambridge laboratories, the Sub-Committee thought that it might assist Dr. Evans if they exposed some of their standard specimens coated with his paints to immersion at Caernarvon. Dr. Evans agreed to this suggestion and six pairs of specimens coated with different paint combinations were included in the January, 1942, tests. One specimen of each pair was painted over a freshly pickled surface; the other had previously been pickled and weathered for one month at Birmingham.

The paints had no anti-fouling properties, so they became covered with a copious marine growth at an early stage of exposure. This rendered accurate inspection of the protective properties impracticable. Consequently, half the specimens, the pickled and weathered ones, were removed in July, 1942, after 25 weeks' exposure; the exposure of the duplicates is being continued.

The result of the final examination of the specimens removed in July, 1942, is given in Table XX. The changes in weight on exposure and cleaning, *i.e.*, the weights of paint lost,[1] were less than

[1] There would have been no point in stripping the specimens to determine the loss of steel, as it was obvious that this would be small or negligible.

the total weights of paint applied, and confirmed what was evident on inspection, namely, that the majority of the painting systems had good protective properties and that over the period of test the best system, *E*140/*V*7, was comparable with the best proprietary protectives. The worst systems were on the point of failure, which would render them approximately equal to a moderate proprietary system.

TABLE XX.—*Series V. Caernarvon. Results of Tests on New-Type Protective Paints (Dr. U. R. Evans).*

Order of Merit.[1]	Paint Reference No.		Weight. Oz. per sq. ft.		Condition after Exposure.
	First Coat.	Second Coat.	Total Dry Paint.	Loss on Exposure.	
1	*E*140	*V*7	0·61	0·03	No significant rusting.
2	*Q*92	*Q*92	1·39	0·38	Pinhead rust stains.
3	*E*140	*Z*16	0·67	0·43	Pinhead failures and rust stains.
4 {	*E*77/6	*E*77/6	0·74	0·27	Front, pinhead rust stains. Back, 90% rust stains.
	*E*140	*E*140	0·94	0·56	Pinhead failures in brush marks.
6	*E*140	*Z*17	0·54	0·42	Rusting and flaking, front 8%, back 3%.

[1] Based on visual inspection.

The further development of these types of paint is being intensively studied at Cambridge, and attempts are being made to devise an all-purpose paint in which protective and anti-fouling properties would be combined.

PART VI.—SERIES VI. COMPOSITIONS FORMULATED BY THE PAINT RESEARCH STATION (DR. L. A. JORDAN).

(a) *Experimental Details.*

Through the kindness of Dr. L. A. Jordan, another series of formulated paints was prepared at the Paint Research Station for inclusion in the tests begun at Caernarvon in January, 1942. The main object of this series was to explore the possibility of developing simple compositions incorporating certain substitute medium materials to meet a possible development of the supply position. Particular attention was paid to the effects of substituting coumarone resin and lanolin for rosin and linseed oil, respectively, in compositions of the rosin/coal-tar-pitch/linseed-stand-oil type. Tests on compositions in a phenolic-resin medium formulated for hot-application were also included.

Details of the painting schemes are given in Tables XXI. and XXII.[1] Each scheme consisted of two coats of protective and one

TABLE XXI.—*Series VI. Caernarvon. Formulations of Compositions Supplied by the Paint Research Station.*

Medium:	A.	C.	D.	F.	H.	S.
(a) Compositions of Media. Parts by Weight.						
Rosin	20	...	...	...	...	...
Coumarone	...	15	4¼	4¼	...	...
Resins (super-Beck 1001 & 2000, 1 : 1)	...	...	...	...	5	...
Coal-tar pitch	2	1½	4¼	4¼	...	...
Linseed stand-oil	...	...	...	...	2	...
Linseed stand-oil, leaded	5	4	2	...	...	...
Pale boiled linseed oil	...	...	...	...	...	1
Lanolin	...	...	...	2	...	...
Tung oil	...	...	...	...	8	...
(b) Compositions of Protective Paints. Parts by Weight.						
Painting scheme Nos.	1, 2, 3, 4, 5, 21	6, 7, 8	9, 10, 11	12, 13, 14	15	16, 17, 18, 19, 20
Pigment (red iron oxide, 4; atomised lead, 1)	60	60	60	60	73	65
Medium	21	22	22	22	24	35
Thinners	19	18	18	18	3	...

Reference.		A.	C.	D.	F.	H.
(c) Compositions of Anti-Fouling Paints. Parts by Weight.						
a	Painting scheme Nos.	1, 3, 18	6	9	12	15
	Toxins:					
	Yellow mercuric oxide	10	10	10	10	11
	Cuprous oxide	5	5	5	5	6
	Pigment (red iron oxide, 1; Paris white, 1)	47	47	47	47	57
	Medium	21	20	21	21	23
	Thinners	17	18	17	17	3
b	Painting scheme Nos.	4	7	10	13	16
	Toxin: Cuprous oxide	5	5	5	5	6
	Pigment (red iron oxide, 1; Paris white, 1)	55	55	55	55	67
	Medium	21	21	22	22	24
	Thinners	19	19	18	18	3
c	Painting scheme Nos.	2, 5, 19	8	11	14	17
	Toxin: Cuprous oxide	14	14	15	14	17
	Pigment (red iron oxide, 1; Paris white, 1)	48	48	47	48	57
	Medium	20	20	21	21	23
	Thinners	18	18	17	17	3
s	Painting scheme Nos.	20, 21				
	Toxins:					
	Yellow mercuric oxide	14				
	Cuprous oxide	7				
	Pigment (red iron oxide, 1; Paris white, 1)	39				
	Medium	21				
	Thinners	19				

[1] The formulations given here are approximate, but detailed analyses are available in the Sub-Committee's files.

coat of anti-fouling composition. Except in one case, in which the atomised lead was omitted, the same pigment mixture (4 parts of red iron oxide and 1 part of atomised lead) was used in all the protective compositions.

The toxins used in the anti-fouling compositions were yellow mercuric oxide and cuprous oxide. The concentrations were varied as follows :

	(a)	(b)	(c)	(s)
HgO. %	10	Nil	Nil	14
Cu_2O. %	5	5	15	7

In most cases the anti-fouling compositions were made up in the same medium as the protective composition of the same scheme; they were pigmented with equal parts of red iron oxide and Paris white.

In all, 21 painting schemes were tested. Each was applied to duplicate specimens of freshly pickled steel.

TABLE XXII.—*Series VI. Results of Tests on Compositions Supplied by the Paint Research Station.*

(a) Painting Schemes, Reference Nos. and Total Dry Paint.[1]

Medium.	Anti-Fouling Paint. a.	b.	c.	s.
A [2]	1/0·83	...	2/0·69	...
	3/0·58	4/0·53	5/0·48	21/0·58
C	6/0·96	7/0·75	8/0·78	...
D	9/0·98	10/0·91	11/0·96	...
F	12/0·91	13/0·88	14/0·75	...
H	15/9·20	...	...	...
S/A [3]	18/1·01	...	19/0·83	20/0·93
S/H [3]	...	16/6·18	17/4·42	...

(b) Grading at 16 Weeks.[4] Anti-Fouling.

Medium.	Anti-Fouling Paint. a.	b.	c.	s.
A	G	...	M	...
	M	b	b	G
C	M	b	b	...
D	M	b	b	...
F	b	b	b	...
H	b	...	...	...
S/A [3]	M	...	b	G
S/H [3]	...	b	b	...

(c) Grading at 16 Weeks.[4] Protection.

Medium.	Anti-Fouling Paint. a.	b.	c.	s.
A	b	...	b	...
	b	b	b	b
C	G	M	M	...
D	M	M	M	...
F	M	M	b	...
H	b	...	...	...
S/A [3]	b	...	b	b
S/H [3]	...	b	b	...

(d) Loss in Weight, 25 Weeks. Oz. per sq. ft.

Medium.	Anti-Fouling Paint. a.	b.	c.	s.
A	0·77	...	0·40	...
	0·86	0·38	0·40	0·90
C	0·13	0·18	0·18	...
D	0·32	0·29	0·29	...
F	0·18	0·19	0·22	...
H	0·08	...	...	...
S/A [3]	0·96	...	0·86	0·88
S/H [3]	...	0·02	0·08	...

[1] Indicated thus 1/0·83. Scheme No. 1; 0·83 oz. of dry paint per sq. ft., *i.e.*, total dry weight of two coats of protective scheme No. 1 and one coat of anti-fouling paint *a*.

[2] The protective paints of schemes Nos. 1 and 2 contain no atomised lead in the pigment.

[3] The protective paint is in medium *S*. The anti-fouling paints are in media *A* and *H*, respectively.

[4] G = good; M = moderate; b = bad.

(b) *Results.*

All the painting schemes fouled rapidly. After 12 or 16 weeks' immersion most of them were so heavily covered with fouling that accurate inspection of the paint film was impossible. Very heavy blistering was observed in most cases. In fact, the phenolic-resin/tung-oil anti-fouling composition applied hot in schemes Nos. 15, 16 and 17 parted company with the underlying anti-corrosive coat, so that barnacles and other marine growth were observed growing profusely on both the inside and the outside of the anti-fouling film. It is now clear that the amounts of toxins added to the anti-fouling compositions of the (*a*), (*b*) and (*c*) series could not have been expected to prevent fouling in the conditions of immersion at Caernarvon, for which at least 30 toxin units are necessary.[1] Anti-fouling composition (*s*), which contains 35 toxin units, might have been expected to do so, and, in fact, it did withstand fouling better than the others.

The first conclusion, therefore, is that none of the schemes tested is of any great value in preventing fouling. On return to the laboratory, however, it was found that the protective properties of several of the painting schemes were reasonably good. This will be clear from Table XXII., in which results are given for the gradings up to 16 weeks and for the losses in weight after 25 weeks' immersion.[2]

Omitting compositions in media *H* and *S*/*H*, where the low losses in weight observed are undoubtedly connected with the heavy weight of the hot-applied coatings, the best results as regards protection were obtained with schemes Nos. 6, 7, 8 and 12. Their performance is equal to or better than that of proprietary compositions graded as good in series I. and II. Protectives Nos. 6, 7 and 8 were formulated in a $15:1\frac{1}{2}:4$ coumarone/coal-tar-pitch/leaded-stand-oil medium and No. 12 was in a $4\frac{1}{4}:4\frac{1}{4}:2$ coumarone/coal-tar-pitch/lanolin medium. It may be concluded that coumarone can be substituted with advantage for rosin and lanolin for linseed oil in protective compositions of the rosin/coal-tar-pitch/linseed-oil type. Further research along these lines would be advantageous, particularly if more attention were paid in Great Britain to the development of harder and more reliable coumarone resins; care is necessary, too, to ensure that the lanolin does not soften the paint film too much. On the other hand, for anti-fouling purposes, the original rosin/coal-tar-pitch/leaded-stand-oil medium *A* has proved superior to all substitute media tested.

[1] *See* Section B, Part III.(*f*)(2).

[2] The gradings are deduced from index figures calculated for the first four inspections at 4, 8, 12 and 16 weeks; the standard of classification into categories, very good, &c., is approximately the same as for series IV. (*cf.* Section B, Part IV.). The losses in weight refer to single specimens only after stripping the paint, *i.e.*, they represent the weight of steel corroded.

As already mentioned, the experimental hot-applied phenolic-resin paints *H* failed badly; in addition, some of these coatings were not completely dry at the end of the tests. Despite these facts practically no corrosion of the steel had occurred. This is partly due to the thickness of the coating, but is also in line with the known excellent protective properties of this class of paint, whether formulated for cold- or hot-application.

PART VII.—IMMEDIATE EXPERIMENTAL PROGRAMME.

This Report of the Sub-Committee's experimental work on ships' bottom compositions is now almost up to date, and little remains save to give a brief account of tests now being put in hand and of the course that future investigations may be expected to take.

It will be realised from what has been written that the development of improved anti-fouling compositions is closely linked with that of improved protective compositions. It is also clear that the efficiency of an anti-fouling composition is determined by the nature and amount of toxins present in relation to the characteristics of the medium in which they are incorporated. Hence, fundamentally

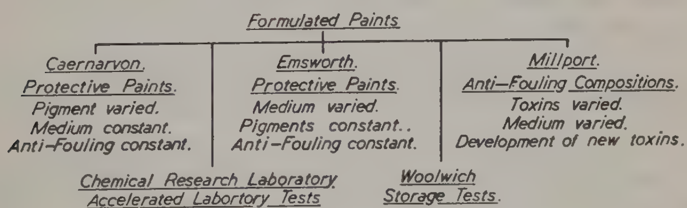


FIG. 8.—Immediate Experimental Programme.

the search for improved formulations for ships' bottom compositions can be broken down into three separate fields of enquiry, as shown in Fig. 8, which represents in a diagrammatic form the activities of the Sub-Committee planned for the immediate future. Subject to such modifications as may prove desirable as the work proceeds, the general organisation will be as follows:

(*a*) Work will be concentrated on formulated paints prepared specially for the investigations, with a view to developing approved formulations as rapidly as possible.

(*b*) Three testing stations will be used for field tests: Caernarvon, Millport and Emsworth. The last of these will be set up shortly by the Admiralty Corrosion Committee under the direction of Dr. I. G. Slater.

(*c*) A series of tests will be conducted at Caernarvon in which the main variable will be the pigmentation of the protective composition,

the same medium being used throughout and the same anti-fouling composition applied over each protective composition. This series of tests, series VII., has already been begun (September, 1942), and a few details are given below (Part VIII.).

(*d*) A series of tests will be conducted at Emsworth in which the main variable will be the medium used for the protective compositions. A limited number of alternative pigments will be used in each medium; these will be common throughout and the same anti-fouling composition will be used in all cases. Arrangements for these tests are now in hand.

In addition, a number of repainting tests on the proprietary compositions exposed in series I. and II. will be made with the object of building up a thick film of protective paint as rapidly as possible and of comparing the efficiencies of the anti-fouling compositions over these thick films. To this end specimens will be prepared *inter alia* by coating initially with (*a*) two coats of anti-corrosive and one of anti-fouling composition and (*b*) six coats of anti-corrosive and one of anti-fouling composition. In case (*a*) the specimens will be removed after two months' immersion, cleaned, allowed to dry and repainted in the same manner; this process will be repeated at two-monthly intervals. The effect of red-lead priming coats beneath a wide range of types of compositions will also be studied.

(*e*) Concurrently with researches (*c*) and (*d*) the fundamental study of toxins and of anti-fouling compositions will be continued at Millport by Dr. J. E. Harris, along the lines indicated in Section C of this Report.

(*f*) Nine painting schemes will be common to the raft tests at all three stations and will serve as controls. Accelerated laboratory tests will be made on these and other paints at the Chemical Research Laboratory, Teddington, using the rotor immersion method (*see* Section B, Part III.(*h*)).

(*g*) Storage tests at ordinary and at tropical temperatures will be made to test the keeping qualities of all paints prepared for the research, in the latter case with the collaboration of the Research Department, Woolwich.

Part VIII.—Series VII. Effect of Pigment in the Protective Paint.

The painting schemes used for the tests on the effect of pigment were all three-coat systems, consisting as before of two coats of protective and one coat of anti-fouling composition, but the same anti-fouling composition was used throughout. The main part of the series consisted of 77 protective paints and the common anti-fouling composition, which were formulated by Mr. F. Fancutt and prepared by him in the Paint Laboratory, the London, Midland and

Scottish Railway Company's Research Department, Derby. The same medium was used for all the protective paints; this was a modified phenolformaldehyde/tung-oil varnish. The pigments used are listed in Table XXIII. Eight of them were used singly; in addition, there were 38 binary and 31 ternary combinations of them.

TABLE XXIII.—*Series VII. Caernarvon. List of Pigments Tested.*

a. Red lead	*g.* Aluminium	*p.* Witherite
b. White lead	*h.* Red iron oxide (natural)	*q.* Zinc chromate
c. Basic lead sulphate	*j.* Zinc oxide	*r.* Zinc tetroxy-chromate
d. Bauxite residue	*k.* Mineral black	*s.* Chromated zinc
e. Barytes	*m.* Zinc dust	*t.* Lithopone
f. Graphite	*n.* Barium chromate	

The anti-fouling composition contained 8% of mercuric oxide and 16% of cuprous oxide in an oil-modified phenolic-resin plus ester-gum base, pigmented with red iron oxide.

Another eight formulated painting schemes were supplied through the courtesy of Bakelite, Ltd. These consisted of protective paints incorporating some of the Derby pigments (the same raw materials were used) in high-grade phenolic-resin media. The Derby anti-fouling composition was applied over these too.

All tests were made in duplicate. One specimen of each pair had been weathered for 3 months and was wire-brushed before painting. The other was pickled in cold dilute hydrochloric acid, according to the Admiralty procedure, and exposed to the weather for 4 or 5 days; it was also wire-brushed before being painted.

The specimens were exposed at Caernarvon between September 10 and 20, 1942. Other tests on the effect of surface condition and on improved paints prepared by Dr. U. R. Evans (*see* Part V. above) were commenced at the same time, but details of these may be left to a future Report.

PART IX.—OTHER TEST SERIES.

In conclusion, a few remarks may be made concerning other series of marine corrosion experiments which, although not primarily concerned with ships' bottom compositions, have a bearing on the subject. These are:

(*a*) Tests on various protective metallic coatings for steel conducted at Gosport and Caernarvon.

(*b*) Immersion tests at Gosport and Plymouth on unprotected ordinary and low-alloy steels.

(a) *Gosport. Metallic Coatings.*

In 1939, the Protective Coatings Sub-Committee made arrangements for a wide series of tests on protective coatings for steel other than paints. These were chiefly of the metallic type and included coatings of non-ferrous metals such as zinc, aluminium, cadmium, tin and lead, applied by various processes and in different thicknesses to 15 in. × 10-in. specimens of ordinary mild steel, $\frac{3}{8}$ in. thick. Although that Sub-Committee was chiefly concerned with atmospheric exposure tests, arrangements were made for a small number of tests on selected coatings under conditions of complete immersion in sea water at the suggestion of the Admiralty representative.

The first tests were carried out at Gosport, where specimens were exposed beneath the pontoons supporting the landing stage in April, 1941, with the kind assistance of the Borough Engineer, Mr. A. Barlow, A.M.I.C.E. The conditions of exposure are such that it is impracticable to examine the specimens at frequent intervals, but trial frames of specimens were removed in October, 1941, and April, 1942, after 6 months' and one year's exposure, respectively. The specimens on these frames consisted of two types of zinc coating—hot-galvanised and sprayed, respectively—and one aluminium coating (sprayed), the tests being made in duplicate. As in the raft tests at Plymouth and Caernarvon, the specimens were insulated from the steel frames by means of a system of insulating sleeves and bushes.

It should be made clear that all these specimens were exposed bare, *i.e.*, with no paint over the galvanising or other metallic coating. When the specimens were removed, the steel frames carrying them were found to be heavily fouled with sea-slugs and squirts; there was practically no weed and only a few minute barnacles. There was a striking difference in the fouling of the aluminium and the zinc-coated specimens. The former were as heavily fouled as the frames; indeed, the deposit was so heavy that it contained small crabs and sand. On the other hand, at 6 months the only fouling on the zinc-coated specimens was a few small barnacles and a little short weed. The contrast is evident in Fig. 21, which shows the specimens at the time of removal after one year's immersion. The difference is probably associated with the toxic properties of zinc.

Particulars of the coating weights and of the losses in weight of the specimens, after cleaning off fouling and corrosion products, are given in Table XXIV. It is evident that these zinc and aluminium coatings should continue to protect the steel for some considerable time, in agreement with the fact that visual inspection revealed no sign of rusting on any specimen. Some blistering of the aluminium coating was noted at the final examinations, although this seemed to have occurred between the layers of the metallic coating, and protection was not impaired. In general, the zinc coatings were smooth, apart from some shallow pin-holing of the sprayed specimens.

TABLE XXIV.—*Gosport. Interim Results of Immersion Tests on Aluminium- or Zinc-Coated Steel.*

Coating.		Loss in Weight. Oz. per sq. ft.	
Type.	Weight. Oz. per sq. ft.	6 Months.	12 Months.
Aluminium.			
Sprayed	0·98	0·01	−0·16 [1]
Zinc.			
Hot-galvanised . . .	2·48	0·52	0·75
Sprayed	2·13	0·26	0·71

[1] The weight increased on exposure.

(b) *Caernarvon. Series III. Paints over Metallic Coatings.*

Another series of tests on metallic and other protective coatings was commenced at Caernarvon in July, 1941, when twelve pairs of specimens were immersed. Two had been sprayed with bitumen or bitumen plus rubber, three were painted with two coats of red-iron-oxide/oil paint and the remainder with three coats of naval compositions, finishing with an anti-fouling coat. Details are given in Table XXV.

TABLE XXV.—*Series III. Caernarvon. Behaviour of Paints over Metallic Coatings on Steel.*

Metallic or Other Coating.		Paint.		Loss in Weight, Cleaned. Oz. per sq. ft.	Life to Failure by Fouling. Weeks.
Type.	Weight. Oz. per sq. ft.	Type.	Weight. Oz. per sq. ft.		
Bitumen, sprayed	18·48	None	...	...	6
Bitumen + rubber, sprayed	10·00	,,	...	...	7
Aluminium, sprayed	0·86	Red-iron-oxide/oil paint, 2 coats	0·33	0·19	7
Zinc:					
Hot-galvanised	2·52	,, ,, ,,	0·25	0·72	18
Sprayed	1·97	,, ,, ,,	0·30	0·70	16
None:					
Pickled; cold dilute hydrochloric acid	...	Naval composition, 3 coats	0·91	1·22	35
Pickled; Footner process	...	,, ,, ,,	0·95	0·63	36
Aluminium, sprayed	0·94	,, ,, ,,	0·95	0·37	51
Lead, electrodeposited	4·91	,, ,, ,,	0·98	0·42	>54
Zinc:					
Hot-galvanised	2·52	,, ,, ,,	0·84	0·70	>54
Sherardised	0·66	,, ,, ,,	0·88	0·57	>54
Sprayed	2·17	,, ,, ,,	0·96	0·54	>54

Chief interest attaches to the behaviour of the naval compositions over the metal-coated steel. The performance of this painting scheme was materially enhanced by all the coatings tested, as is

evident from the data given in Table XXV. for the lives of the anti-fouling composition, which were computed from the results of inspections in the manner described in Part II. (5) above. With paint applied over coatings of lead or zinc, the life exceeded 54 weeks, as compared with 35 weeks for pickled steel. This is confirmatory evidence of the benefit of having a satisfactory anti-corrosive basis for anti-fouling compositions. As will be seen from Table XXV., the losses in weight on exposure, which represent the differences between the initial painted weights and the final weights after cleaning,[1] are less in all cases than the total weight of the dry paint film. Hence, little corrosion of the metallic coatings has occurred. On inspection, in most cases these were sound and showed no sign of rust, except that appreciable rusting had taken place on the sherardised specimens, which carry the lightest coat of zinc, and a slight amount of rusting on one of the specimens coated with electro-deposited lead.

The life of the anti-fouling paint was less on the aluminium-coated specimens than on the other metal-coated ones. As with the bare specimens at Gosport, the fouling was noticeably less on the zinc-coated specimens (and on the lead-coated ones too) than on the aluminium-coated specimens. This is shown in Fig. 22, in which photographs of the various specimens at the time of removal are reproduced. The difference between aluminium and zinc coatings was even more pronounced in the case of specimens painted with red-iron-oxide/oil paint alone, obviously an unsuitable paint for resistance to salt-water immersion.

There is one other point of interest. Reference is made in Table XXV. to specimens pickled by the normal Admiralty procedure, immersion in 5% by volume hydrochloric acid at room temperature, and to specimens pickled by the Footner process. In the latter procedure the mill scale is removed by immersion in 5% sulphuric acid at 60–65° C., the steel is rinsed by dipping twice into water at this temperature and is finally immersed for 5 min. in a bath containing 2% of free phosphoric acid and 0·3–0·5% of iron phosphate at 85° C. This leaves a film of iron phosphate on the surface, which is a good basis for paint.[2]

Although there was no marked difference in the resistance to fouling of these two pairs of specimens, it was noted during exposure that the paint was adhering better to the specimens pickled by the Footner process and that they were less rusted than those pickled in cold dilute hydrochloric acid. Determinations of the losses in weight confirmed this conclusion, one member of each pair being removed in April, 1942, after 41 weeks' immersion, and the duplicates when the bulk of the specimens were removed in July, 1942, after

[1] The paint was not stripped from these specimens, as they were repainted over the old paint with the same compositions and re-exposed in September, 1942.

[2] A detailed description of the process is given by H. B. Footner in the Fifth Report of the Corrosion Committee, *loc. cit.*, p. 369.

54 weeks. The data are given in Table XXVI. This, of course, is an isolated observation, and the matter is being studied further.

TABLE XXVI.—*Series III. Caernarvon. Comparison of Specimens Pickled in Cold Dilute Hydrochloric Acid and by the Footner Process.*

Duration of Test.[1] Weeks.	Pickled, Hydrochloric Acid.			Pickled, Footner Process.		
	Total Dry Paint. Oz. per sq. ft.	Loss on Exposure. Oz. per sq. ft.		Total Dry Paint. Oz. per sq. ft.	Loss on Exposure. Oz. per sq. ft.	
		Cleaned.	Stripped.		Cleaned.	Stripped.
41	0·90	1·42	0·65	0·94	0·75	0·21
54	0·91	1·01	0·44	0·95	0·51	0·32

[1] The more corroded specimen of each pair was removed first. Hence the smaller losses in weight at 54 weeks as compared with 41 weeks.

(c) *Gosport. Bare Irons and Steels.*

From time to time the question is raised as to whether there is any intrinsic difference in the resistance to corrosion by sea water of the ordinary ferrous materials of construction, *e.g.*, ingot iron, wrought iron, mild steel, copper-bearing and other low-alloy steels, &c. Some evidence on this subject has been obtained in the course of the Sub-Committee's investigations, and it may be of interest to summarise this briefly.

In February, 1937, 80 standard specimens, 15 in. × 10 in. × $\frac{3}{8}$ in., were immersed under the landing stage at Gosport. These consisted of 20 specimens each of ordinary steel, 0·5% copper steel, ingot iron and Scottish wrought iron. The specimens were shot-blasted before test. They were arranged on 10 frames, each carrying two specimens of each material, distributed in various positions beneath the landing stage. The test was continued until May, 1938, when the specimens were removed after 1·2 years' immersion.

At the conclusion of the test four things were observed :

(i) The specimens were heavily covered with marine growth.

(ii) The rust beneath the marine growth was black, *i.e.*, was incompletely oxidised. This raises the question whether heavy fouling may not shield steel from rusting by excluding oxygen from it.

(iii) Over large areas there was a white deposit in direct contact with the metal which was found to consist essentially of calcium carbonate. The deposit had protected the metal beneath it, and these areas stood out in relief from the general surface by distances not exceeding 0·01 in.

(iv) There was no appreciable pitting other than a slight general honeycombing of the surface which was too shallow to be measured with a spherometer.

The losses in weight of the four materials are shown in Table XXVII. These are mean values for 20 specimens; the maximum

TABLE XXVII.—*Gosport. Rates of Corrosion of Bare Steel, &c., in Sea Water.*

Material.	Annual Corrosion Rate.	
	Oz. per sq. ft.	Mils.
Structural mild steel:		
Ordinary	3·2	4·9
Copper-bearing, Cu 0·5% . .	3·3	5·0
Ingot iron	3·3	5·1
Scottish wrought iron . . .	2·8	4·2
Mean	3·1	4·8

deviation of individual values from the mean was approximately 8%. There is no difference within the experimental error between the rates of rusting of ordinary steel, copper-bearing steel and ingot iron, but the rate for Scottish wrought iron is distinctly less, about 15%, than that for the other materials.

(d) *Plymouth. Bare Ordinary and Low-Alloy Steels.*

A wider range of irons and steels was compared in a more recent series of tests conducted on the Plymouth raft from March to October, 1940, covering 7 months' immersion. Through the courtesy of Monsieur L. Séguenot, specimens of nearly all the commercial steels included in the field and laboratory tests of the Corrosion Committee of the Office Technique pour l'Utilisation de l'Acier (O.T.U.A.) were made available for this purpose. Although steels from other sources were included in the Plymouth tests, discussion will be confined here to this group of steels.

The O.T.U.A. steels consisted of ordinary and low-alloy structural steels classified under four headings, as shown in Table XXVIII.:

(*a*) Ordinary soft carbon steels.
(*b*) Soft copper-bearing steels.
(*c*) Ordinary medium-soft carbon steels.
(*d*) Medium-soft copper-chromium steels.

The breaking load of the steels in classes (*a*) and (*b*) was approximately 25 tons per sq. in. and that of the steels in classes (*c*) and (*d*) 32 tons per sq. in.

The specimens measured approximately 8 in. × 8 in. × ⅛ in., and the mill scale was removed from them before exposure by pickling in 20% sulphuric acid at 40° C. with an inhibitor. They

TABLE XXVIII.—*Plymouth. Rates of Corrosion of Ordinary and Low-Alloy Steels in Sea Water.*

Ref.	Steel. Description.	Steel. Analysis. %.	Annual Corrosion Rate. Oz. per sq. ft.	Annual Corrosion Rate. Mils.
	A. Ordinary Soft Carbon Steels (Carbon 0·03–0·11% ; *Copper* 0·04–0·11%).			
	Basic Bessemer.			
*A*1	Rimming, ordinary [1]	Silicon 0·20	3·7	5·7
*A*2	Rimming, high-phosphorus	Phosphorus 0·14	3·7	5·7
*A*3	Rimming, high-phosphorus and sulphur	Phosphorus 0·10 ; sulphur 0·07	3·9	5·9
	Open-Hearth.			
*A*4	Rimming, ordinary		3·7	5·7
*A*5	Rimming, from hematite pig		3·6	5·6
*A*6	Killed	Silicon 0·10 ; aluminium 0·04	3·7	5·6
*A*7	Killed, from hematite pig	Silicon 0·13 ; aluminium 0·04	3·5	5·4
		Mean	3·7	5·7
	B. Soft Copper-Bearing Steels (Carbon 0·03–0·11% ; *Copper* 0·48–0·53%).			
	Basic Bessemer.			
*B*1	Rimming		3·9	6·0
*B*2	Rimming, high-phosphorus	Phosphorus 0·15	3·4	5·2
*B*2 *bis*	Rimming, high-phosphorus and sulphur	Phosphorus 0·14 ; sulphur 0·07	3·3	5·1
	Open-Hearth.			
*B*3	Rimming		4·0	6·1
*B*4	Killed, from hematite pig	Silicon 0·04 ; aluminium 0·01	3·8	5·8
*B*6	Dead soft, 0·08% molybdenum	Carbon 0·03 ; aluminium 0·01 ; molybdenum 0·08	3·7	5·7
		Mean	3·7	5·7
	C. Ordinary Medium-Soft Carbon Steels (Carbon 0·22% ; *Copper* 0·03–0·05%).			
	Open-Hearth.			
*C*1	Killed	Silicon 0·12 ; aluminium 0·04	3·7	5·7
*C*2	From hematite pig	Silicon 0·03 ; aluminium 0·03	4·1	6·3
		Mean	3·9	6·0
	D. Medium-Soft Copper-Chromium Steels (Carbon 0·10–0·22% ; *Copper* 0·41–0·65% ; *Chromium* 0·42–0·51%).			
	Basic Bessemer.			
*D*1	Killed	Silicon 0·16	4·0	6·2
*D*2	Killed, high-phosphorus	Silicon 0·18 ; phosphorus 0·11	3·6	5·5
	Open-Hearth.			
*D*4	Killed, from hematite pig	Silicon 0·23	4·2	6·5
*D*5	Killed, from hematite pig, high-phosphorus	Silicon 0·24 ; phosphorus 0·11	3·8	5·8
*D*6	Killed	Silicon 0·22	4·2	6·4
		Mean	4·0	6·1

[1] The O.T.U.A. description is obviously incorrect, since the steel contains 0·20% of silicon.

were secured to the exposure frames by rust-resisting steel bolts, which were insulated in the usual way. All tests were made on duplicate specimens. After exposure, the specimens were cleaned

and wire-brushed. The remaining rust was removed by immersing them in dilute sulphuric acid containing an inhibitor. This cleaned the surface very easily and the amount of hydrogen evolved was negligible. After a final weighing, the surface of the specimens was examined.

(i) *Fouling.*—Copious marine growth was observed on all the specimens when they were removed from the water; this included weed, mussels, limpets, anemones and calcareous worms. The fouling on individual specimens was compared, and it was concluded that there was no significant difference that could be attributed to differences in analysis of the steels.

(ii) *Pitting.*—No pitting was observed on examination after exposure other than a slight general roughening of the surface.

(iii) *Loss in Weight.*—The losses in weight of the various steels are given in Table XXVIII. They have been converted by simple proportion into ounces per square foot per year; the equivalent rates of corrosion in thousandths of an inch (mils) are also given. The mean experimental error for the whole series, expressed as half the percentage difference between duplicates, was 3·1%. Since greater errors were observed in individual cases, it is inadvisable to attach importance to apparent differences between different materials of less than say 10%.

There is no marked variation in the corrosion resistance of this range of commercial steels. If mean values are taken for all the steels in each of the four main groups, it is found that the rates of corrosion of groups (*a*) and (*b*), ordinary soft carbon steels and soft copper-bearing steels, respectively, are identical. It follows that the addition of a small percentage of copper to steel has no effect on its corrosion resistance under these conditions. The mean values for groups (*c*) and (*d*), medium-soft steels of ordinary and of copper-chromium qualities, respectively, are also practically identical. These values are slightly higher than those for the steels of series (*a*) and (*b*), but it is doubtful whether the difference is significant. It may be concluded that the joint effect of small additions of both copper and chromium to these steels has had no marked effect.

(iv) *Conclusions.*—The general conclusion to be drawn from these tests and the earlier ones at Gosport is that it is improbable that there is any wide difference in the corrosion rates of the common irons or steels when immersed in sea water. It is certain that such differences will be entirely eliminated when, as is necessarily the case in service, the steel surfaces are covered with paint. Presumably, under normal circumstances the rate of corrosion of a bare steel in sea water is determined by the rate at which oxygen reaches the surface. The fact that the rust under the marine growth is black indicates that this rate of supply is insufficient to enable the maximum corrosion rate to be attained. Under these conditions it is not surprising that comparatively small differences

in the composition of the steel do not affect its corrosion rate, but the possibility is not precluded that a different state of affairs might arise for surfaces to which the rate of oxygen supply was greater, *e.g.*, steel plates moving rapidly through the open sea. It is also possible that fouling tends to interfere with the diffusion of oxygen to the steel surface.

Section C.—Anti-Fouling Investigations.[1]

By J. E. HARRIS, Ph.D. (Investigator).

Most of the work referred to in this Section has been carried out at the laboratory of the Scottish Marine Biological Association, situated in the Clyde estuary at Millport, Isle of Cumbrae. Two experimental rafts are maintained there at different sites, characterised by two somewhat different types of fouling.

In addition to the valuable help given by individual Members of the Sub-Committee, acknowledgment is due to Miss F. A. Stanbury and Mr. H. Barnes, who have spent their spare time at Plymouth Technical College working on the problem, and to Dr. M. F. Mare, of Newnham College, Cambridge, and Mr. K. A. Pyefinch, of University College, Nottingham, who during the summer of 1942 worked at Millport with the author. The voluntary help of this team of workers as well as of many others who have assisted in various portions of the work is greatly appreciated.

The prevention of fouling is a problem which requires a very thorough study from the biological as well as from the chemical point of view, since a detailed knowledge of the organisms concerned together with their mode of life is required in order to interpret differences between surfaces fouled under different conditions of toxicity, season and duration of exposure, &c. A study of the physiology of the organisms may also make it possible to devise specific methods for preventing their attachment and growth.

From the biological point of view, the fouling of a surface presents a problem in colonisation both by plants and by animals which is being carefully studied. It will be advantageous to give a brief description of the organisms involved, in order that the subsequent account of the work can be more easily followed.

Part I.—The Fouling Organisms.

When a sheet of non-toxic material is immersed in the sea at certain times of the year a community of organisms rapidly appears upon it. Included among these organisms may be :

[1] Received November 6, 1942.

(i) *Marine bacteria*, many of which secrete a coherent slimy film over the surface. This film has been shown to differ considerably in its properties when formed on different types of surface and on toxic surfaces of different degrees of toxicity.

(ii) The young stages (spores) of *seaweeds* of many types. Some of these proceed to develop directly into long single or

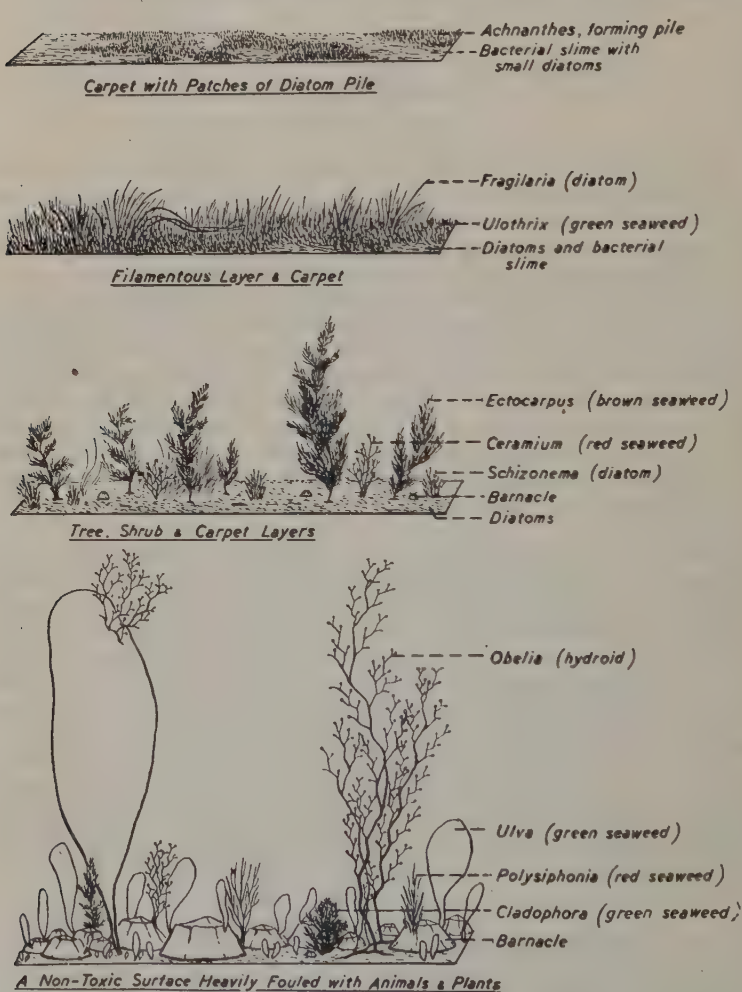


FIG. 9.—Types of Community on Paint Surfaces at Millport (actual size). These diagrams illustrate levels of development on patches differing in age and toxicity. The communities formed on panels exposed in other localities or on ships' hulls in service may differ from those shown.

branched threads attached only at their bases; others grow out over the surface to form a broad attachment disc before they commence to sprout free shoots.

(iii) *Diatoms*—minute plant cells occurring singly, in chains or in masses, living in branching tubes of mucus or growing at the free ends of mucous stalks. These may form a thick slimy layer over the surface, or long trailing brown threads similar in appearance to certain seaweeds.

(iv) The *larval forms of many sessile marine animals.* These are all microscopic free-swimming organisms, capable at a certain sharply defined stage in their development of settling on a suitable surface, to which they attach themselves by a cementing organ. When the attachment is accomplished a profound change in form occurs; this metamorphosis produces an adult organism, of which the mode of life is quite different from that of its larva. As the animal grows, more and more cementing material is laid down beneath its increasing surface of contact, and the attachment rapidly becomes so secure that only severe mechanical damage will dislodge it. This sequence of events is found in *barnacles*, *calcareous tubeworms*, *ascidians* (sea-squirts) and *polyzoa*. *Mussels* settle in a form not unlike the adult, attaching themselves by cementing threads. The attachment and growth of *hydroids* follows a more plant-like pattern; the larva settles and grows out over the substratum as a series of branching tubes, from which at intervals arise the stalks bearing the main body and feeding organs of the animal.

When such a surface has reached the stage of heavy fouling and is examined under water, the general impression gained is that of a miniature wood or forest of vegetation containing numerous animal forms. Such a community is shown in diagrammatic form in Fig. 9. On analysis it can be resolved into the following fairly well defined layers:

(*a*) *A basal carpet*, comprising the bacterial slime, many of the diatoms and the attachment systems of seaweeds and hydroids.

(*b*) *A filamentous layer*, growing up from the carpet, including filamentous seaweeds and diatom chains. This type of growth is found at certain seasons of the year to be the dominant form on plates which are not heavily fouled.

(*c*) *A shrub and tree layer*, composed of taller and frequently tufted growths of the larger seaweeds and hydroids. On a heavily fouled surface the presence of a dense growth of this type progressively eliminates other plants and diatoms and prevents the growth of those which may settle later. Such *biological exclusion* must be carefully allowed for in assessing the toxicity of a surface by the presence or absence of a particular organism. The division of this layer into a shrub

and a tree layer differing in height is mainly significant as representing different stages of growth of the same organisms.

(*d*) *Animals* found in the community may include any or all of the forms listed in (iv) above.

The population found on a panel at any one period is determined by the stage reached in a process of progressive colonisation. The development of the community is determined largely by seasonal changes in the number of infective organisms and also in the case of a toxic surface by the toxicity at the period of maximum settlement of each species.

From the shipowners' point of view, the first two categories (*a*) and (*b*) comprise what are usually called "slime," and the last two (*c*) and (*d*) correspond to the more obvious "fouling."

A detailed biological analysis made in the above manner is of direct practical importance, first in providing data for the determination of the effect of various toxins upon particular kinds of fouling organisms, and secondly in indicating complicating factors, such as seasonal effects and biological exclusion effects, which may otherwise cause errors in interpretation. Seasonal effects are caused by differences in numbers and types of spores and larvæ available at any one period, since many fouling organisms have a restricted breeding period (*see* Fig. 10).

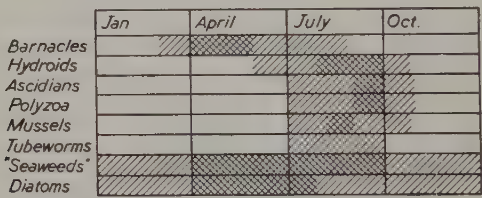


FIG. 10.—Caernarvon and Millport, 1941–42. Seasonal settlement of fouling organisms. Heavier settlement is indicated by cross-hatching, the period of lighter infection by single-hatching.

The widely differing sensitivities of different organisms to the metallic toxins commonly used in anti-fouling paints are clearly shown in Table XXIX., which summarises a few of the results obtained from analyses made in the above manner. The frequency of occurrence of each organism has been assessed on an arbitrary numerical scale, and each figure represents the average of observations on six communities.

From Table XXIX. it may be seen that *Laminaria* (the large brown oarweed seen at low tide on the shore) and *Ulva* (the sea lettuce) are very sensitive to metallic poisons, while red seaweeds are somewhat less so. *Schizonema* (a colonial diatom which lives in mucous tubes) and *Ectocarpus* (a small fluffy brown seaweed)

are much less sensitive than the above; *Ectocarpus*, for example, which is common in ship fouling, is not completely eliminated by the most toxic paint of the series. The small amount of *Ectocarpus*

TABLE XXIX.—*The Effect of Varying Concentrations of Copper and Mercury upon Fouling Organisms.*

Assessments made after 23 weeks' immersion, from February to July, 1942.

Mercury. %.	Copper. %.											
	0.	6.	12.	18.	0.	6.	12.	18.	0.	6.	12.	18.
	Laminaria.				*Ulva.*				*Red Seaweeds.*			
0	1·2	0	0	0	2·9	0·8	0·2	0	2·8	1·3	0·7	0·2
5	0	0	0	0	0	0	0	0	2·2	1·2	0	0
10	0	0	0	0	0	0	0	0	1·2	0·2	0	0
	Schizonema.				*Ectocarpus.*				*Obelia.*			
0	0·7	1·9	0·9	1·7	0·3	2·0	2·4	2·3	2·1	1·7	0·2	0
5	2·7	0·6	0	0	1·8	1·9	1·0	0·7	0	0	0	0
10	0·8	0	0	0	1·3	0·9	0·2	0·2	0	0	0	0

and *Schizonema* present on paints containing no copper or mercury is an example of biological exclusion described above; the large numbers of other organisms present have prevented the successful development of these two forms.

Similar results have been obtained for animal fouling organisms; for instance, as shown by the data in Table XXIX., *Obelia* (one of the common hydroids) is very sensitive to mercury and copper.

Where conditions are such that the principal fouling organisms are limited to one or two types, the above results suggest that the most practical anti-fouling coat may prove to be one specially designed for the elimination of such types, which may be characteristic of the itinerary or period of working of the vessel concerned.

Another point brought out by biological analysis is illustrated in Table XXX. The barnacle populations on equal areas of

TABLE XXX.—*Barnacle Populations on Paints of Different Toxicity.*

Area analysed in each case: 8 in. × 4 in.
Total time of exposure: 22 weeks, February–August, 1942.
Anti-fouling paints containing no copper.

Barnacle Size. Mm. Age. Weeks. Exposure Period. Weeks.	>8. 22–8. 0–14.	8–2. 8–4. 14–18.	2–0. 4–0. 18–22.	Total Barnacle Population.
Mercury Content of Paint. %.	Number of Barnacles.			
0	352	52	0	404
5	4	44	60	108
10	4	20	24	48

three paints of different toxicity have been divided into size groups which correspond to different ages of barnacles. On the non-toxic paint 352 barnacles had settled during the first 14 weeks of exposure, while during this same period only 4 had settled on paints containing 5% or 10% of mercury (as oxide). Between 14 and 18 weeks, 44 settled on the 5% mercury paint and only 20 on the 10% mercury paint, while in the last 4 weeks of exposure (18–22), 60 settled on the former and only 24 on the latter. Evidently the paint surface containing 5% of mercury began to lose its toxicity after 14 weeks, while that containing 10% of mercury was still appreciably poisonous after 22 weeks of exposure. The absence of small barnacles from the non-toxic plates in later stages of the exposure is explained as a simple case of biological exclusion; the larger barnacles present covered the whole of the surface, and there was no space left for the later settlement of younger organisms.

Table XXXI. furnishes another example of this technique applied to paints containing very high percentages of toxin (24% of

TABLE XXXI.—*Barnacle Populations on Paints of Different Permeability.*

Area analysed in each case: 8 in. × 4 in.
Total time of exposure: 22 weeks, February–July, 1942.
Both paints contained 24% of copper (as Cu_2O) and 15% of mercury (as HgO).

Barnacle Size. Mm. Age. Weeks. Exposure Period. Weeks.	>8. 22–8. 0–14.	8–2. 8–4. 14–18.	2–0. 4–0. 18–22.	Total Barnacle Population.
Bitumen/Oil Ratio in Medium.	Number of Barnacles.			
8	28	44	228	300
2	0	0	56	56

copper and 15% of mercury, as oxides) in two different media. The media used were oil-bitumen varnishes of two different oil lengths.[1] The paints made with the varnish of high bitumen content allowed considerable numbers of barnacles to settle even during the first 10–14 weeks of immersion. In view of the very high toxin content, this effect could not have been due to early loss of toxicity and must indicate a lack of permeability of the paint medium. The second paint, containing a smaller proportion of bitumen, completely prevented barnacle settlement for the whole of the first 18 weeks of exposure.

Later in this Report a number of Tables showing the performance of different types of paints will be given. Tables XXX. and XXXI.

[1] The "length" of an oil-bitumen varnish refers to its proportion of oil to bitumen; a long oil varnish has a high oil content.

are merely intended to indicate the way in which a detailed biological analysis of the community can assist in evaluating the performance of an anti-fouling composition.

PART II.—STAGES IN FOULING.

(a) *The Bacterial Slime.*

The earliest stage of fouling on many paint surfaces is the production of a bacterial slime, which may vary in thickness and in mechanical properties (coherence and mechanical stability), depending on both the type of bacteria responsible for its production and the paint on which it is produced. It has been possible to grow marine bacteria successfully in media containing copper in concentrations greater than 1 : 100,000, which is well above what is required to saturate sea water, so that it is not surprising that all anti-fouling films so far investigated possess such a bacterial film. Nevertheless, the *amount* of slime developed furnishes an index of the toxicity of the surface on which it forms, provided that the surfaces compared are similar in other respects. Table XXXII. contains the results of an experiment on these lines. It shows that on five paints all made in a similar paint medium the amount of slime developed was closely related to the anti-fouling effect of the paint. That the relation is only true for similar types of surfaces is indicated by the figures given in Table XXXII. for

TABLE XXXII.—*Slime Formation on Paint Surfaces.*

F = Weed fouling. S = slime.

Date of Exposure.	Duration. Days.		Type of Paint or Surface.							
			Non-Toxic Paint.	5% Cu.	20% Cu.	15% Hg.	17% Cu, 10% Hg.	10% Cu Wax + Rosin.	Copper Resinate.	Glass.
10/7/42 to 20/7/42	10	F[1]	× ×	—	—	—	—	—	×	×
		S[2]	2·0	1·75	1·0	0·75	0·75	2·5	2·5	0·5
10/7/42 to 27/7/42	17	F[1]	× × ×	—	—	—	—	× ×	× ×	× × × ×
		S[2]	2·9	2·7	1·75	1·5	1·3	4·75	7·75	0·5
20/7/42 to 3/8/42	14	F[1]	× × ×	×	—	—	—	× × ×	× ×	× × ×
		S[2]	5·25	3·0	3·0	1·25	1·0	3·75	7·75	0·5

[1] The amount of weed fouling is indicated by:
— nil. × trace. × × slight amount. × × × fair amount. × × × × considerable amount.

[2] The units employed in the measurement of "slime" in Table XXXII., Fig. 11 and Fig. 12 are all different, since different methods of assessment were used in each case. In Table XXXII. the amount of slime was estimated by a gross visual comparison of the surfaces; in Fig. 11 the units are based on a quantitative determination of the amount of dyestuff leached from the preparation; in Fig. 12 the units are based on a microscopic count of the numbers of organisms found in the slime.

three other surfaces on which the relation of slime to fouling differs appreciably from those of the preceding five examples. A coating of a waxy composition containing rosin and cuprous oxide and also a coating of commercial copper resinate both produced very heavy slimes, even though they were slightly anti-fouling in their action, while plain glass slides, though fouling rapidly, developed very little slime.

It has been found possible to measure the amount of slime formation quantitatively with considerable accuracy by staining the slime film with methylene blue. The colour absorbed is subsequently leached out and the amount of dyestuff estimated colorimetrically. Using this technique, which is also applicable to painted surfaces, the amount of slime formation can be accurately estimated within a period of 24–48 hr. after immersion. The graph, Fig. 11, shows the development of slime on a glass surface immersed in sea water for 4 days, as measured in this manner. These experiments may have considerable practical importance in view of the speed with which differences between paints of varying toxicity become apparent. Not only is it possible by this method to determine the toxicity of the surface within a very short period, but, since the seasonal effect is much less marked for slime formation than for fouling, it is possible to carry out experiments on these lines all the year round—work need not be limited to the fouling season.

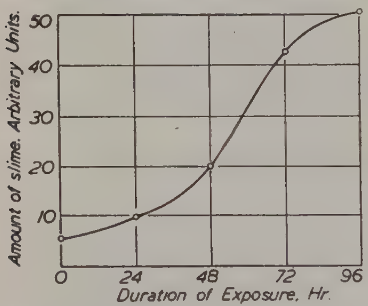


FIG. 11.—Development of slime on a glass surface in sea water in the laboratory (*see* footnote No. 2 to Table XXXII.).

The relationship between slime formation and the settlement of other organisms is important. Experiments with glass surfaces have shown that a bacterial slime of appreciable thickness is not a necessary preliminary to the settlement either of plants or of animals. It is also true that the primary bacterial slime film is not necessarily permanent, since more or less extensive stripping may take place.

Previous published work has suggested that the presence of a thin bacterial film definitely favours the attachment of larger organisms. The significance of the part played by slime in the early stages of fouling thus needs further elucidation. In this connection it may be noted that on the panels at Caernarvon slimes due to bacteria or diatoms have always been recognisable before any of the larger algæ were apparent.

The chemical implications of slime formation are also important.

Certain waxy paints, which form very heavy slime layers, do not develop large-scale fouling for very long periods. It is possible that on such paints the slime film (which frequently contains resistant diatoms as well as bacteria) may accumulate the poisons diffusing from the paints to a sufficient extent to protect the surface against settlement of the larger organisms.

(b) *The Diatom Flora.*

The diatom growths which form freely on specimens immersed on exposure rafts occur less commonly on ocean-going ships, and they may play only a minor part in practical problems of fouling. They are, however, useful to the investigator, since they also provide a means of estimating the toxicity of the surface soon after its immersion in sea water—long before any visible signs of plant or animal fouling on a large scale appear. This point is illustrated in Fig. 12, where the amount of slime formed on various test panels

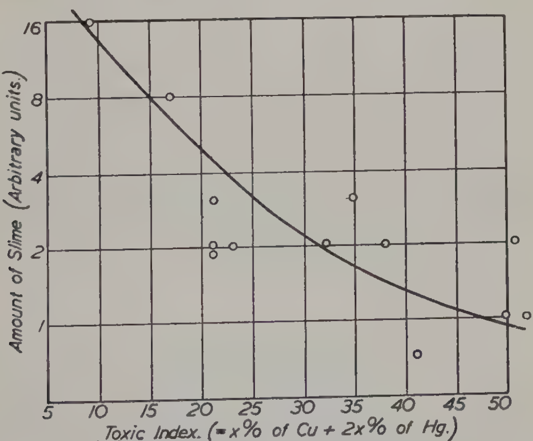


FIG. 12.—Caernarvon. Correlation of slime formation and paint toxicity (*see* footnote No. 2 to Table XXXII.).

exposed from May to November, 1941, is plotted against the toxic index of the paints applied to them. The correlation is sufficiently good to raise the hope that by the use of such indicator organisms in combination with accelerated breakdown methods for the paints, anti-fouling tests which might normally require a year to perform could be carried out within a week or two. As some diatoms reproduce at all seasons, with increasing knowledge of the properties of the organisms concerned it should also be possible to use this method at all times of year.

(c) *The Process of Attachment of Higher Organisms.*

All evidence goes to show that the toxicity of a surface has little effect on the growth of an organism once firm attachment has taken place. If methods could be found which would prevent permanent attachment, considerable progress would be made towards a solution of the anti-fouling problem. The prevention of permanent attachment may be achieved either by the inclusion in the paint of substances exerting a repellent or lethal action in the settling stages or, alternatively, by the inclusion of substances which prevent the adhesion or setting of the cementing substances. The second possibility necessitates a study of the chemical properties of the cement, the mechanism of its adhesion and the subsequent setting process. Initially the cement secreted by the barnacle larva is being studied, as the barnacle is one of the most important of the persistent fouling organisms. It has been possible to rear the common fouling barnacle from its free-swimming larva to the fixed stage in the laboratory, which greatly facilitates the study of the fixation process. The cement produced by the barnacle is chemically similar to a secretion produced by many of the larger crustacea. Since such organisms provide much larger quantities of material for investigation, the opportunities for the study of the cementing process have thus been substantially increased, and experimental work along these lines is in progress. Work is also being carried out on the secretions of other animals, such as calcareous tubeworms and hydroids, which may produce a cement having chemical properties similar to that of the barnacle. It is planned to carry out other experiments on plant material where the cementing substances may be rather different.

Part III.—Anti-Fouling Compositions.

(a) *Inorganic Poisons.*

In order to elucidate the general principles underlying the action of anti-fouling compositions, a large number of raft tests, involving the use of both inorganic and organic poisons in various types of paint medium, are in progress. The performance of some 500 of such formulated compositions has so far been determined, and the principal results of these experiments are summarised in Tables XXXIII. to XXXIX. A preliminary series of determinations made in 1941 indicated that, among the inorganic poisons commonly used in anti-fouling paints, mercury was almost twice as effective against weed fouling as copper (weight for weight), while arsenic was almost ineffective. Against animals, particularly barnacles, mercury was relatively much more effective than against seaweed, being at least three times as effective as copper against barnacle fouling. Arsenic appeared to be similarly ineffective against shell

fouling. These results were extended and confirmed in a series of experiments in 1942, which are summarised in Tables XXXIII. and XXXIV.

TABLE XXXIII.—*Anti-Fouling Compositions. Combined Effects of Copper and Mercury as Cuprous and Mercuric Oxides.*

Each value is an average of approximately six tests.
Period of test, 23 weeks, February–August, 1942.

Copper. %.	Mercury. %.	Weed.	Hydroid.	Barnacles.
0	0	5·52	2·17	5·67
	5	3·63	0·17	0
	10	3·35	0	0
6	0	4·68	1·2	2·8
	5	3·07	0	0
	10	1·38	0	0
12	0	3·75	0·17	1·0
	5	1·33	0	0
	10	1·00	0	0
18	0	3·1	0	0
	5	2·00	0	0
	10	1·83	0	0

The relative effectiveness of copper, mercury and arsenic in preventing plant and animal fouling was similar to that found in the earlier experiment, though the effect of mercury against barnacle fouling was even greater than had previously been supposed; 5% of mercury was as effective as, and probably even more so than,

TABLE XXXIV.—*Anti-Fouling Compositions. Effect of Arsenic (as As_2O_3).*

Period of test, 23 weeks, February–August, 1942.

As_2O_3. % : Number of tests :	0. 24.	5. 22.	10. 23.
Weed	2·77	2·96	2·98
Hydroid . . .	0·38	0·36	0·17
Barnacles . . .	0·79	0·55	1·00

18% of copper in this respect. Table XXXV. shows that the effect of a constant weight of different copper toxins is apparently determined principally by their copper content, the high effect of the copper bronze and cuprous oxide contrasting in this respect with the lower anti-fouling effectiveness of the sulphocyanide and the still lower value for Paris green.

The solubility in sea water and the effective surface area of the pigment particles, however, also play a part in determining the effectiveness of copper pigments in normal paint media.

TABLE XXXV.—*Anti-Fouling Compositions. Effects of Different Copper Toxins.*

Period of test, 20 weeks, March–August, 1942.
10% of toxin was added to the anti-fouling composition in each case.

Toxic pigment : Number of tests :	Cu. 12.	Cu_2O. 12.	CuCNS. 12.	Paris Green. 12.
Cu in pigment. %	100	89	52	24
Weed fouling	2·98	3·09	3·19	3·53

(b) *Organic Poisons.*

The high toxicity of certain organic compounds (such, for example, as are used in insecticides, fungicides, &c.) has prompted a study of their action on marine animals and plants both in the laboratory and when combined in paint films. Nearly a hundred such compounds have been tested on marine organisms, and some forty of these have been incorporated in anti-fouling compositions. The importance of this work lies in the fact that it may be possible to replace the expensive mercury oxide, which is in very short supply at present, by a synthetic organic compound which is more readily available. The possibility of replacing cuprous oxide is, perhaps, less important, and tests with organic compounds have therefore included paints containing cuprous oxide as well as paints made with the organic poison only.

The results obtained with these compounds have been anomalous. Almost without exception the forty compounds tested in paint films have been at least as toxic as copper to marine organisms in sea-water cultures, and some of them have been far more toxic than mercury when tested in this manner. On the other hand, the anti-fouling efficiency of paints formulated with these organic poisons varies from a *negative* value—the organic substance appears to act as an attractant or as a growth stimulant—to a *positive* anti-fouling efficiency, which is, however, far less than would be expected from the toxicity of the compound when dissolved in sea water. There is no obvious relationship between chemical constitution and toxicity; the only generalisation which can be made at the moment is that substances which possess an irritant as well as a lethal action are likely on the whole to be more effective than those which do not possess irritant properties.

The equilibrium between the poisons present in the paint film and in the adjacent volume of sea water is likely to be of importance in determining the anti-fouling efficacy of the film. Methods have

been developed for the micro-analysis of copper and mercury in sea water, and chemical studies of the rate of leaching from the paint film of ionic copper and mercury and also of organic compounds are in progress.

(c) *The Paint Medium.*

The discovery of suitable poisons is only one part of the solution to the anti-fouling problem; an equally important part is played by the paint medium, which has to provide for durability of the coating together with continuous availability of the poison contained in it. The two requirements are difficult to satisfy at the same time. The problem of durability is being examined with the assistance of paint technologists; the various mechanisms by which the toxin can be made available by the medium are also receiving very careful study. Tables XXXVI. and XXXVII. illustrate the effect of the paint medium on the anti-fouling properties of paints containing cuprous and mercury oxide.

Table XXXVI. illustrates the ineffectiveness of a highly

TABLE XXXVI.—*Anti-Fouling Compositions. Effect of Medium.*

Period of test, 23 weeks, February–August, 1942.
Medium 1121 : Linseed-oil/rosin/coal-tar-pitch. Lead drier.
Medium 1111 : Linseed-oil/rosin/blown-bitumen. Lead drier.
Medium 2047 : Gilsonite/tung-oil. Lead, manganese, cobalt driers.

Medium No.: Number of tests:	1121. 35.	1111. 34.	2047. 21.
Weed	2·90	2·90	4·36
Hydroid	0·31	0·29	1·81
Barnacles	0·74	0·82	4·10

impermeable gilsonite/tung-oil medium in comparison with a linseed-oil/rosin medium. The durability of the gilsonite/tung-oil medium is satisfactory, but it is quite unsuitable for an anti-fouling paint. An instructive example is provided by Table XXXVII.,

TABLE XXXVII.—*Anti-Fouling Compositions. Effect of Bitumen/Oil Ratio in Bituminous Media.*

Period of test, 23 weeks, February–August, 1942.

Bitumen/Oil ratio[1]: Number of tests:	2:1. 17.	4:1. 17.	6:1. 17.	8:1. 16.
Weed	3·91	3·88	4·39	4·46
Hydroid	0·18	0·41	0·29	0·375
Barnacles	2·17	1·76	2·06	3·25

[1] A leaded linseed oil was used.

which shows the effect of increasing the relative amount of bitumen in a bitumen/oil-varnish medium containing copper and mercury oxide. The decrease in anti-fouling efficiency when the bitumen/oil ratio is raised above 4 : 1 is clearly shown.

The "permeability" of the paint to the poison can be raised by increasing the total pigment content of the paint by the addition of suitable organic fillers. This is illustrated in Table XXXVIII. The difficulty here is that the increase in total pigment volume beyond a certain point decreases the durability of the paint. If it is possible, by changing the type of medium, to increase the pigment content very considerably, an appreciable improvement in the anti-fouling efficiency of the paint may be expected.

TABLE XXXVIII.—*Anti-Fouling Compositions. Effect of Total Pigment Content.*

Bitumen/linseed-oil medium.

Period of test, 23 weeks, February–August, 1942.

Total pigment content. % : Number of tests :	50. 24.	60. 21.	70. 22.
Weed	4·74	4·08	3·58
Hydroid . . .	0·58	0·05	0·27
Barnacles . . .	3·09	1·86	1·86

Surprisingly little is known of the actual chemical mechanism by which a poison such as copper produces its anti-fouling action. It is found that many of the higher fouling organisms (as well as marine bacteria) are not poisoned by a saturated solution of ionic copper in sea water; some mechanism must therefore exist whereby the organism receives an extra lethal dose. The chemical equilibrium between the copper pigment, the free fatty acid in the medium and the sea water is being investigated. Surface toxicity (which may involve a repellent as well as a lethal action on certain organisms) may be maintained (*a*) by direct penetration of fat-soluble copper compounds into the organisms, (*b*) by local acidity which leads to an increase in the saturation equilibrium of ionic copper, or possibly (*c*) by a simple supersaturation process. Tests on the rate of leaching-out of copper from proprietary anti-fouling paints suggest that many of them appear to rely for their toxic properties on an almost catastrophic mechanical breakdown of the paint film, which is bound to be associated with excessive toxin loss and poor durability. Fundamental studies of the type indicated above may point to means of overcoming this difficulty.

(d) *The Effect of the Protective Undercoat.*

It is obvious that if the protective undercoating fails to adhere to the hull or to the overlying anti-fouling film, the composition will be rendered useless, since the anti-fouling paint will be completely

removed by flaking. This phenomenon is of common occurrence in proprietary as well as in experimental anti-fouling paint systems. But there are more complicated interactions of the two paint layers.

Table XXXIX. shows the fouling on a series of very impermeable bitumen-oil paints containing high percentages of metallic toxins, painted over four different anti-corrosive undercoats. The results are surprising but very clear-cut; the best anti-fouling efficiency is procured over the worst undercoat. This anomaly probably has a very simple explanation: The breakdown of the undercoat in its initial stages weakens the impermeable anti-fouling coating sufficiently to permit the enclosed toxins to escape and exert their poisonous action. The anti-fouling medium used was sufficiently

TABLE XXXIX.—*Anti-Fouling Compositions. Effect of Anti-Corrosive Undercoats.*

Period of test, 23 weeks, February–August, 1942.
Anti-corrosive paints; all bitumen-oil media:

0·1 with red oxide only.
0·2 with red oxide and atomised lead paste.
0·4 with lead chromate, silica and zinc oxide.
0·52 with aluminium powder.

Anti-fouling paint, 24% of copper as Cu_2O and 15% of mercury as HgO in bitumen-oil medium.

Anti-corrosive No.: Number of tests:	0·1. 6.	0·2. 27.	0·4. 18.	0·52. 36.
Weed	2·38	3·58	3·81	4·70
Hydroid . . .	0	0·26	0·50	0·36
Barnacles . . .	0	1·45	1·83	3·04
Blistering	52	37	32	2

strong mechanically to prevent total breakdown for some time; ultimately, however, the whole paint system, including the bad undercoating, flaked off completely. It is clear that if a normal type of anti-fouling coating had been used instead of a highly impermeable bitumen-oil type, the loss of toxins from the weakened film would have been so great that the whole system might have failed by fouling before complete breakdown had occurred.

Where the undercoat permits rusting which penetrates the anti-fouling coat in spots, rapid loss of toxins occurs at these points and fouling organisms readily settle on the rust spots. A study of the correlation of fouling with rusting on 92 painted panels[1] showed that fouling always *follows* rusting and that there is no evidence that the presence of fouling organisms on a panel brings about subsequent rusting (except where the organisms may become detached, carrying away with them the adherent paint film).

The inorganic anti-fouling toxins are all highly corrosive agents,

[1] Caernarvon, series II., proprietary paints.

and an inefficient anti-corrosive undercoat will have its breakdown accelerated in presence of the anti-fouling composition. The best anti-fouling system requires a perfect anti-corrosive undercoating coupled with a completely compatible anti-fouling coating which is durable but presents a continuously toxic surface, preferably with the minimum possible loss of toxic material into the surrounding sea water.

PART IV.—THE FOULING OF SHIPS.

Upwards of sixty samples from ships have been examined, and, with the exception of vessels frequenting shallow waters, they have, on the whole, a more limited flora and fauna (*i.e.*, fewer species) than are found on test panels exposed on rafts. Part of this difference is probably due to the limited flora and more limited opportunities for infection in the usual ports of call. Those seaweeds, like *Ectocarpus* and older plants of *Enteromorpha*, which have a spreading attachment organ will probably withstand the force of the water movement better than others which are less securely attached and which may be torn off during the motion of the ship. *Ectocarpus* and *Enteromorpha* are both very frequent members of the fouling growths on ocean-going vessels; even though the plants of *Ectocarpus* themselves may not be visible, their attachment systems persist, and these may provide anchorages for weed of other types to settle on later. This suggests that if the specific organisms which provide these "moorings" can be eliminated, it is possible that a great deal of the weed fouling will fail to attach successfully.

While every effort is made to visit ships in dock as often as possible, and while it is realised that small- and large-scale tests on ships must be the ultimate criterion of the success or failure of an anti-fouling coating, this is difficult to achieve in war time. The Sub-Committee would very much welcome the planned co-operation of any shipowners who would be prepared to send for examination samples of marine fouling from ships when they are docked, and/or to provide facilities for tests to be made on sea-going vessels.

The possibility of the elimination of specific types of organisms (frequently referred to above) suggests that the most practicable anti-fouling coat may prove to be one specially designed for the condition of work of the individual vessel—taking into account such factors as speed, itinerary, length of time in port, most convenient periods for docking, &c. Data concerning foul ports, exceptional cases of fouling and similar matters of general interest represent a further valuable source of information, in the collection of which the Sub-Committee would welcome the fullest possible collaboration of the shipping industry.

DISCUSSION.

Dr. G. D. Bengough, F.R.S. (Chairman of the Sub-Committee), in introducing the Report, said : I have already on two occasions in the last few weeks discoursed at some considerable length on the work of the Marine Corrosion Sub-Committee.[1] You will hardly wish me to speak a third time on the subject, and so I shall leave the presentation of the Report very largely to our two investigators, Dr. Hudson and Dr. Harris. I wish merely to point out that the present Report is a preliminary one. It gives a picture of the problem as it appears to the Sub-Committee and an account of the work done by the Sub-Committee down to about the end of last September.

This problem is a very complicated one indeed. It involves biological studies as well as physical. When we started this work we had to define the problem before we could attack it, and that was difficult to do. In this preliminary Report we do not attempt to give solutions of the problem; it is too early to do so; solutions —or preliminary solutions, at any rate—may be given in the next Report. We have already done a considerable amount of work which will be embodied in a second Report, but I do not want to anticipate that in any way at all.

We have already had two considerable discussions by a large number of people on this preliminary work, and it so happens that when we were discussing it before the Institution of Naval Architects a good many of the speakers were Members of the Sub-Committee. We hope that to-day many Members of the Institute and visitors who are not Members of the Sub-Committee will discuss the Report, and will have new ideas and criticisms to put forward; we shall welcome both.

Dr. J. C. Hudson (Official Investigator, Birmingham), who introduced Section B, dealing with marine corrosion tests, said : I should like to refer to series IV. of the tests, which is concerned with the effect of surface condition and of temporary protective coatings applied to prevent rusting during the preliminary weathering period on the behaviour of ships' bottom compositions applied to steel plates. Results obtained up to the time when the Report was written are given in Table XVI. These results can now be made clearer by expressing them in terms of the lives to failure by corrosion of the various specimens, which can be computed from data which have become available since that time. Thus the conclusions given on p. 387 P concerning the behaviour of painting scheme *A* can be restated as follows :

[1] G. D. Bengough and V. G. Shepheard, "The Corrosion and Fouling of Ships," Institution of Naval Architects, Apr. 15, 1943. G. D. Bengough, "Hull Corrosion and Fouling," North-East Coast Institution of Engineers and Shipbuilders, Apr. 16, 1943.

(i) In the case of six surface treatments in which temporary coatings of red lead paint were applied, the average life exceeded 50 weeks. For six similar surface treatments where red iron oxide paint was used instead of red lead, the average life was 17 weeks.

(ii) The life of painting scheme *A* on freshly pickled steel was 18 weeks, but when the pickled surface was weathered for 105 days before the composition was applied the life increased to more than 60 weeks. If a coat of red lead paint was put on between the pickling and the painting proper but with no exposure to the weather, a life of 49 weeks was obtained; this fell to 14 weeks when red iron oxide paint was used instead of red lead. Plates that were weathered in the as-rolled condition for 105 days and then painted had a life of 31 weeks.

It should be emphasised that these statements refer only to this particular painting scheme, and it is probable that for other painting schemes we may record results at variance with them. The point is that, whereas, as a result of the work of the main Corrosion Committee and of the Protective Coatings Sub-Committee, we now understand fairly fully the effect of surface condition on the behaviour of paints on steel exposed to atmospheric corrosion, we are still far from clear as to its effect in the case of under-water paints. Much further research will be necessary before we can be sure of our conclusions; but it is already apparent that the effect of rust, as distinct from mill scale, underneath a paint film is not nearly so serious on an under-water paint as on a paint exposed to atmospheric corrosion. We have shown conclusively that for atmospheric work the best procedure is to apply paint to a perfectly descaled suface, and that any rusting between the descaling process and painting produces a deterioration in the results; but this is not necessarily the case for marine compositions. The results obtained so far show that in some cases, but not all, rust beneath the paint film has improved performance, possibly by increasing the adhesion of the anti-corrosive composition.

A preliminary investigation of the consistency of ships' bottom compositions, referred to on p. 359 P, has now been made by the Sub-Committee, and it will be helpful to mention the conclusion at which we have tentatively arrived. Dr. Slater collected samples of compositions from two of H.M. dockyards which, in the opinion of the foremen painters who were responsible for their application, represented the range of consistency from very thick to very thin. Through the kindness of Mr. Fancutt, these samples were investigated in the Paint Research Laboratory of the London, Midland and Scottish Railway Research Department at Derby. Mr. Fancutt concluded from this examination that it would be impracticable to fix an upper limit for consistency, but that it was possible to fix a lower limit, which would have the effect of eliminating

those compositions which had insufficient body to be capable of giving adequate protection. The figure suggested by Mr. Fancutt is 25 sec. for the efflux time of the first 50 c.c. of paint from a full No. 4 Ford cup at 70° F. Although it may be found desirable to modify this figure somewhat in the light of further practical experience, it is obvious that some limit of this type, which would eliminate excessively fluid compositions, would have a generally beneficial effect.

Dr. J. E. HARRIS (Official Investigator, Millport, Isle of Cumbrae, Scotland) then presented Section C, dealing with the anti-fouling investigation.

Dr. W. H. HATFIELD, F.R.S. (Vice-President; Brown-Firth Research Laboratories, Sheffield): This subject of fouling is a problem of the first importance from the standpoint of the war. We already had a Marine Corrosion Sub-Committee of the Corrosion Committee under Dr. Bengough which was operating very well, but, in view of the importance of the subject at the present time, we took up the subject of fouling. That involved considerable expenditure on research, and Sir William Larke's organisation agreed to contribute to the support of the new research. We then approached the Admiralty; they said that this was one of the researches which they wanted to see carried out, and they at once made an excellent contribution. We then saw the shipowners, who contributed handsomely; this was largely due to the enthusiastic assistance of Dr. Dorey, of Lloyd's Register of Shipping. We then came to the conclusion that the shipbuilders might still have a lasting interest in their product; they showed very great interest, and they have given us a very handsome annual contribution to the research. All this finance is likely to continue, and it is therefore a matter of very great gratification to me to be able to tell you that here is a research of primary national importance being conducted with no anxiety at all as regards the money required for the work.

I see the work at first hand, and I am sure that there is no better example of the collaboration of diverse sciences than we have here. You all know Dr. Bengough for the research work which he has done for many years, and you have had experience of Dr. Hudson's excellent work as the director of our Corrosion Committee's researches. Dr. Harris is a brilliant young biologist from Cambridge whom we were fortunate enough to enlist in this work. Added to this, we have some twenty scientists engaged on this work, so that you will see that, without any exaggeration, this Sub-Committee scientifically is one of the strongest committees in the world. Whilst you may think, therefore, that fouling is a little removed from the basic iron and steel industry, yet it is a great affliction of one of the products resulting from our work, and

I am sure we have done rightly as an Institute and as a Research Council in backing this work.

Some people say that fouling is thoroughly understood, and they will sell you anti-fouling compounds and say "Put that on the ship's bottom and there will be no trouble." But it is not so. Fouling is a very serious matter to-day. I know that vast numbers of specimens are under test at the present time; the combinations of compositions and of methods of application are very great in number, and it will naturally take a long time before the whole of the work can be properly sorted out. Nevertheless, I believe that some of the results of this research should be of actual service even during the present war.

To stimulate discussion, I should like to mention that there is one very interesting development of ship plate manufacture which has been before us intermittently for a long time. It is said, and I believe with truth, that there was less difficulty in protecting ship plates made a generation and more ago than there is to-day. I shall not express my view of the matter except to say this, that the speed and temperature of finishing and other factors are different to-day from what they were then. If we could have as part of this discussion some contributions by people with long experience in the rolling of ship plates, I should like to have the last forty years of production of ship plates analysed from the standpoint of the nature of the scale and its capacity for adherence to the plate or otherwise in relation to preservation.

Mr. J. Sinclair Kerr (Member of Council; Lancashire Steel Corporation, Ltd., Irlam, near Manchester): I am glad to take upon myself the privilege of opening the general discussion on this comprehensive paper on the protection of ship plates against corrosion.

We must remember that the steel of to-day, more especially in normal times, has been made under more and more controlled conditions caused by the development of research and technical improvements at all stages, including rolling, all of which reflect on the quality of the surface of the steel, the mobility of gaseous products and adherent mill scale. How have these changes affected the problem of marine corrosion? I think all this has something to do with what Dr. Hatfield has just said.

Take the case of rails. Many years ago they were not made to the stringent specifications that they are to-day, and yet our attention is now and then drawn to rails having long-wearing properties, rails which have given astounding performances in the track. Is not the degree of purity which we have achieved at the moment now acting against us? I would like to put that point to the melting shop managers and metallurgists.

Mr. F. C. Dyche-Teague (Detel Products, Ltd., Greenford, Middlesex): We are interested in anti-fouling, but we are really

manufacturers of anti-corrosives. One thing which strikes me about anti-fouling, however, is that there does not seem to have been a great deal of improvement in the materials used for thousands of years, bearing in mind what we know about their use in the Mediterranean in Phœnician days; the Phœnicians used arsenic, and perhaps even mercury, and we still use them to-day. Our only hope of improvement seems to lie in these organic compositions of very much greater toxicity mentioned by Dr. Harris.

There is another point which arouses my interest. The barnacle seems to adhere well to almost every surface—rubber, wood, iron, ebonite, steel and so on—with the exception of certain algæ. Although I have heard that certain compositions have been made which contained a decoction of these algæ, there appears to be no record of whether they were successful or not. It is probably the surface condition of the algæ which was effective in preventing attachment, but it is strange that they should have that property, which no other material seems to possess.

Mr. H. R. Wood (Messrs. Storry Smithson & Co., Ltd., Hull): Every investigator has found that arsenic (As_2O_3) has little anti-fouling properties; however, it may have other virtues. It is a rust inhibitor; such arsenites as zinc arsenite should be tried in the first anti-corrosive coat.

Accepting the principle of coagulation of the albumen, mercury is very good, copper is good (not equal to mercury) and arsenic has almost no effect on that property, unless the arsenic is combined with some phenyl derivative as phenyl arsenious oxide. Mercury and copper have been found by the trade to be the best of all anti-foulers tried.

Criticism of the test panels is that much less paint was applied as compared with that generally applied to a ship. Steel panels treated with acid, washed and cleaned to a surface like glass and painted with a 2-in. brush take much less paint than do the rough surfaces of ships' plates. It is surprising how much paint is absorbed on painting a ship carrying many old previous coats of paint. In my opinion, for practical purposes, the test panels should have had about the same weight of paint per square foot.

The Report recommends that a toxic index of 30 is necessary (say, 20 parts (20 toxic units) of copper and 5 parts (10 toxic units) of mercury), whereas many compositions with lower toxic indices have given excellent results. It is admitted that in some tropical waters—the West Coast of Africa—conditions are undoubtedly severe. Much depends upon the length of stay in ports in this area.

A British patent covers the use of copper oxalate, and perhaps this and the citrates or tartrates of copper are worth investigating, as it has been assumed that an acid property is required to stop the first adherence on the ship of the bacteria or barnacles.

An unusual composition of an Australian was tried by my

firm; this was based on the idea of producing arsine and stibine by the action of sea water on the composition. The danger in making rather than the failure deterred us. Whether any of the poison gases developed for gas warfare could be used with safety might be worth considering.

Dr. W. H. Hatfield, F.R.S.: This is a fitting opportunity to debate the question whether there has been any change in the character of the surface of plates as they have come out of the steelworks during the last forty years. Anyone with any experience of plates or of mild-steel sections might comment on that to our advantage.

Mr. Vernon Harbord (Messrs. Riley, Harbord and Law, London): Of recent years more and more alloy scrap has gone into furnaces, and very little mild steel is made to-day without some traces of copper and chromium in it. That may have some effect on the adhesion of the scale, and to this extent plates of more modern manufacture may be more liable to corrosion than those of older fabrication.

Mr. A. Robinson (Appleby-Frodingham Steel Co., Ltd., Scunthorpe, Lincs.): I cannot say that I have had experience for forty years in making steel plates, but, after having had a look round the older works, I would say that there is no doubt that the temperature of the plates when they are finished is, in these older works, lower than in the more modern works, and the type of scale is somewhat different. The low-temperature scale is a red one, and the high-temperature scale, of course, is a blue one. There is a difference there.

With regard to the composition of the plates, I think everyone knows that in the last thirty years the inspection of plates, and of all steel, has been very much tightened up, and the phosphorus and sulphur contents are definitely lower than in the old days. Reference has been made to steel rails, and the same thing applies there. In some cases phosphorus has been found to have an effect upon the steel which inhibits corrosion to some extent. Cor-ten steel is better than the copper contents would account for. Again, continual efforts have been made and much money has been spent on new mills, rolls and improvements to give a perfectly smooth surface on plates.

In the old days, moreover, a shipbuilder bought a lot of plates and kept them in his yard, so that by the time he wanted them they were thoroughly descaled and rusted. Nowadays, the shipbuilder sends an order, expects quick delivery and puts the plate in the ship the week after, with practically all the scale on. It may be that the rougher surface in rolling and that obtained by thoroughly rusting took a thicker coating of paint.

Has the modern demand for a quicker turn round in dry-dock created a demand for a thinner paint, which in turn gives a thinner coating and less protection?

Mr. LOUIS RIPLEY (Lloyd's Register of Shipping, Middlesbrough): Mr. Robinson has made a point regarding the time taken to build ships. It is common knowledge that building has been very much expedited, and plates therefore do not get the opportunity of weathering before being incorporated into the structures. In regard to the matter of quality raised by Dr. Hatfield, my view is that there has been no marked deterioration in this respect, and I think it is true to say that the quality is more uniform to-day than ever before. The Society with which I am connected is concerned in peace-time with ship plates produced in every steelmaking country in the world, and I am not aware that material from a particular country could be said to behave less satisfactorily than that from any other country, and it does seem that this is a general problem rather than one involving quality.

On the question of surfaces those of us who have had experience on the Continent know that in Germany, in particular, it is the practice to roll direct from the ingot without intermediate slabbing, and the plates finish with something like a matt surface; it has been claimed by the Germans that this is a better surface for painting. It may be that the German plates do not compare favourably with the British plates in regard to smoothness, but so far as quality is concerned there is little to choose between plates wherever they are made.

Mr. J. SINCLAIR KERR: With regard to Mr. Robinson's remarks, there seems to be room for a discussion on the question of weathering or ageing. Mr. Robinson mentioned that in former years the plates used to lie about in shipbuilding yards for a lengthy time when the surface would become weathered, and quite a different surface would be exposed for painting than is obtained with the plates of to-day, which are used as soon as they are received.

It seems to be true that the war has the effect of bringing us from a quarter to half a century ahead in such matters as qualities of materials and new mixtures. The war gives us a jump forward in technical matters just as it does in the social services. New information on steels is being discovered and developed with remarkable rapidity.

With regard to corrosion, cannot we produce a type of steel or steel surface which will enable us to dispense with paint? The money spent on paint and labour should enable us to produce a plate of a quality which will give the necessary resistance to corrosion without the need for paint. I think the time is ripe for action in this direction.

CORRESPONDENCE.

The Association of Ships' Compositions Manufacturers (London) wrote: Before criticising the Report in detail we consider it advisable to draw attention to a surprising omission. No acknowledgment has been made to those firms in the anti-fouling composition industry who laid open their research laboratories and testing stations to the Sub-Committee when they were arranging to have these trials carried out for the Admiralty. Since several Members of the Committee, at the request of the Admiralty Corrosion Committee, visited the biological department and marine testing station of at least one of our Members, the failure to acknowledge this assistance is all the more remarkable. The general impression from reading this Report seems to be a peculiarly unfortunate one, in that the industry is frequently discredited. Comments that there is no standardisation of quality or consistency give an entirely wrong impression, and that shipowners cannot get what they should is not in accordance with facts. The impression given by the Report that the Sub-Committee, and the Sub-Committee alone, have done the only research work on anti-fouling paints is grossly unfair and, of course, quite incorrect, and the trade would be perfectly justified, on these grounds alone, in protesting against the publication of this Report.

A great deal of work, which in time and money must have been very considerable, has been done on perfectly worthless statistics. To show tables of poison contents of a variety of anti-fouling paints used for different purposes is quite valueless, just as valueless in fact as a table showing the raw materials of both anti-fouling and anti-corrosive paints taken together. The Official Investigator consistently disregards questions of thickness of film. The Report states that no attempt was made to control the weights. The weight of paint applied was left to the discretion of the painter. A less scientific method of investigation would be difficult to imagine, and, as this point is of fundamental importance, the greater part of the deductions made by the Sub-Committee is in our opinion valueless.

Our detailed criticisms of the report are as follows.

Page 348 P, *Paragraph* 1.—The last sentence is obscure and the conclusion that "by buying compositions on the general reputation of particular manufacturers the user by no means ensures that he obtains even the best of the available paints for his particular purpose" is in any case quite unjustified.

Page 348 P (*Protection*).—The prevention of corrosion seems to be more of a problem for the metallurgist to produce steel less subject to corrosion.

Page 348 P (*Anti-Fouling*).—The Sub-Committee would appear to suggest that no previous work on the prevention of fouling has been carried out, whereas a number of commercial firms have carried

out researches for many years, and are far ahead of the Corrosion Committee, having done the work which the Committee is now undertaking some 15 or 20 years ago. In the whole of this Report there is little which is not already known to the industry. Whereas metallurgy and anti-corrosive coatings may be closely associated, how can metallurgy in any way further the study of anti-fouling problems?

The methods of attack recorded under this heading have already been fully investigated by the industry:

(i) Types of organisms responsible for the fouling of ships have already been established.

(ii) and (iii) The biological aspects referred to have been studied and are continuing to be studied by those engaged in the industry.

(iv) Research work is continually being carried on by those engaged in the industry for new and better toxins, in the field of both inorganic and organic chemistry.

(v) The incorporation of toxins in the paint is no longer a problem with which the industry is faced.

Page 348 P, *paragraph* 1, *page* 350 P, *paragraph* 2, *page* 352 P, *Section B*, *paragraph* 1, *page* 357 P, *Part III.*, *paragraph* 1.—From these statements it is clear that anti-fouling composition manufacturers were asked to submit samples for comparative trials which were carried out on behalf of the Admiralty. The Official Investigator, in addition to doing these trials, has had the paints analysed and this Report includes some of the results of these analyses. He makes it clear that these analyses will also help to formulate compositions with the avowed intention of publication.

Page 352 P.—What is meant by the assumption that a composition of any given brand does not remain constant? This may be so, but any difference will be in the way of improvement as a result of manufacturers' own individual research.

Page 354 P, *last* 3 *lines*.—A less scientific method of investigation would be difficult to imagine.

Page 355 P, *paragraph* 2.—It would be interesting to know exactly what significance the Official Investigator attaches to the result obtained by the testing methods of leaving an unpainted "holiday." Does he consider a paint which gives adequate protection on the rest of the plate but allows severe corrosion in the holiday superior or inferior to a paint which gives the reverse result?

Table II.—This Table presumably refers to both anti-fouling and anti-corrosive compositions; such being the case it is of little or no value.

Page 359 P, *end of paragraph* 2.—It is to be noted that their efforts are to reduce the compositions to a few tested formulations which, if followed, would prevent any manufacturer from utilising the results of his own researches, which hardly seems a laudable aim

for a research body. It would be deplorable if, as a result of the issue of a few formulations, the many different qualities now in use with entirely satisfactory results would no longer be available to shipowners to meet their special requirements.

Page 359 P (*Consistency*).—The Official Investigator has exhibited a praiseworthy desire to carry out many tests in a quantitative manner. It is therefore tragic to think that the time taken for all these tests on anti-fouling paints is more or less useless on account of such a fundamental error as failure to control the weight of paint applied. The danger of failure to control the weight of paint applied per unit area was pointed out to the Sub-Committee before testing was started.

Table IV.—The variation in quantity of paint applied at Plymouth showed that the highest had 5·4 times as much as the lowest, while at Caernarvon the highest had 4·6 times as much as the lowest. From these large variations, it is obvious that no satisfactory conclusions can be drawn as to the relative merits of the majority of the compositions tested. Anything less scientific or more inaccurate would be difficult to imagine.

Table V.—In the discussion of the results, the Official Investigator has noted the better performance of anti-corrosive compositions with thicker coats. Yet this factor has been ignored in the application of the anti-fouling compositions.

Table VIII.—The short useful life of the majority of compositions was obviously due to the small weight of paint, but this is no reason for the general condemnation of commercial anti-fouling compositions.

Page 367 P, *last paragraph*.—The statement that fouling is best assessed on repainted specimens is somewhat contrary to experience. We have generally found flaking to be more severe on repainted specimens with paints which do not exhibit this defect in practice. Blistering, flaking and, to a lesser extent, cracking on small-plate trials often bear no relationship to the performance of the same paints under practical conditions.

Page 369 P, *paragraph* 1.—The suggested "toxic index" is too arbitrary, and is valueless unless all toxins are taken into consideration, and their availability, which in turn depends not only on the type of vehicle but also on the weight of paint per unit area. If insufficient is known about the toxins in all the paints, this should not be used to explain the discrepancies in the figures. It is to be noted that no figures are produced taking weight also into consideration. This is somewhat surprising, inasmuch as the Report states that the correlation was better.

Page 369 P, *last paragraph of* (2).—This statement seems to have been made on very scanty evidence.

Table XI.—The big differences in scheme *A* are probably largely due to experimental errors, while the small differences in scheme *B* could only be expected with this very short period of

immersion, with, presumably, the usual very thin coats of paint. We cannot see that any deductions of value can be made from such a Table.

Page 371 P.—We find that small differences in respect of flaking, blistering, peeling and, to a lesser extent, rust on small plates can be very misleading and often bear little relation to what happens in practice, particularly where the paints are of different formulations. A knowledge of the behaviour of paints of various types in practice, as well as on small plates, enables one to get some idea, but working às at present, very much in the dark, the Sub-Committee's deductions are likely to be erroneous, and it should be remembered that about 90% of ships' paintings are over old paint. The tendency to make unwarranted deductions is again shown at the bottom of this page, where it is stated that where paint films had softened they were probably near the end of their useful lives.

Table XIII.—It seems impossible to attach any significance to this Table and the accompanying text. It is not clear what paint is over what, and the only thing that emerges is that the plate that gave bad adhesion in the Plymouth trials was more likely to give poor adhesion when repainted at Caernarvon over its remaining film than was a plate that had given good adhesion at Plymouth. In our view the bad results at Plymouth were almost certainly attributable to using unbaptised plates—the better results at Caernarvon to the fact that the plates had had a christening at Plymouth.

Page 374 P (*Pitting at Holidays*).—This is of somewhat doubtful value, as the majority of paints are applied over old paint. Pitting can be markedly influenced by the nature of the rust nib.

Page 376 P, *top*.—Also some of the more enlightened shipowners have realised the dangers of using red lead underwater. The worst feature of red lead is the throwing off of subsequent coats. This defect often does not show until the paint has been immersed for some considerable time.

Page 376 P (*Experimental Details*).—It is pleasing to note that in the C.R.L. test priming coats are used, but it should be pointed out that if thin coats of paint are applied, particularly in the case of the anti-fouling, the results with regard to disintegration are very misleading.

Page 377 P (*Conclusions*).—It is admitted that the paint films applied to the test specimens were much thinner than those used on actual ships, and therefore could not function in regard to the rate of solution as was intended by the manufacturers, and as would occur in practice.

Page 378 P, *paragraph* (*e*).—This conclusion is erroneous, as it is deduced from thin coats. It is weight of poison per unit area and rate of solution which matter.

Page 378 P, *paragraph* (*g*).—A very unfair implied criticism of ships' bottom composition manufacturers, as every attention is

paid by them in their formulations to obtain a practical working consistency of their products.

Page 378 P, *paragraph* (*h*).—Until more accuracy is introduced into their experiments and proper control exercised, results obtained by the Sub-Committee are of little value, and the relative merits of the compositions tested cannot be assessed.

Page 401 P, *paragraph* (*iii*).—This calcium carbonate formation is generally present at the cathode where galvanic action is taking place.

Pages 405 P–414 P.—The description of fouling organisms is good, and proper attention is paid to seasonal effects and the importance of the biological environment. In this connection the use of the term "biological exclusion" seems quite apt. The differing resistance to poisons displayed by different organisms is referred to, and the way in which this may be linked up with the effect of the biological environment has been noted. The Tables illustrating the value of biological analysis are reasonably clear and well-chosen, if perhaps somewhat meagre. There is no need to criticise the types of paint employed in some of this work, as at this stage, and in this particular, the method is more important than the material, and we fully realise that those responsible for the formulation of the compositions cannot have had the necessary experience in these matters, and it is not surprising, therefore, that the choice of paint media shows, in our opinion, a lack of knowledge of paint technology and of anti-fouling compositions.

The conclusions reached are obviously tentative and it is certain will have to be modified in many respects. The differentiation between bacterial and diatom slimes is not too clear in some places, *e.g.*, in the discussions relating to Table XXXII. and Figs. 11 and 12; it might be that Fig. 11 relates to bacteria and Fig. 12 to diatoms, while Table XXXII. might refer to either or both; there is no clear indication given.

Page 416 P (*Organic Poisons*).—Successful commercial paints with organic poisons replacing mercury are available, and have been available for more than ten years, their experimental stage having been undergone during the four or five years prior to that, that is to say, fifteen years ahead of the Marine Corrosion Sub-Committee, and research work on this subject has been continued without interruption by the industry.

Page 418 P, *end of* (*c*) *The Paint Medium.*—The suggestion that many compositions rely for their toxic properties on mechnical breakdown of the paint film is probably far from the truth but would often be found or deduced where thin coats of anti-fouling compositions of certain types were used on small plates. With thicker coats, such as those recommended by the manufacturers, such mechanical breakdown is unlikely to occur.

Page 419 P, *top.*—The suggestion that flaking is a common occurrence in proprietary as well as experimental anti-fouling paints, in

our opinion, only applies to small-plate trials. Experience shows that this defect, which is often frequent on small plates, is seldom found in practice. It is obvious that if commercial paints were to exhibit this phenomenon to the extent suggested by the Sub-Committee, they would soon be condemned by shipowners and would have little or no sale. This flaking phenomenon, which exhibits itself on small-plate trials, is not generally found when the same paints are used in practice.

The foregoing criticisms are based on very extensive knowledge of the subject. Contrary to the impression conveyed by the Report, research work has been carried on by Members of this Association over a long number of years.

While admitting that very high efficiency has been attained by proprietary ships' compositions, the Report is nevertheless generally framed to imply that those engaged in the industry know little of the subject, and are not capable of producing good compositions. The fact is that compositions very much superior to those in use are available to shipowners who desire them; in other words, the industry is ahead of present demand.

While we do not agree that anti-fouling problems are within the scope of the Marine Corrosion Sub-Committee, general research such as the creation of steel less subject to corrosion, and any investigations of an academic character, would be welcomed and be of general interest to the industry. And, while agreeing that anti-fouling compositions may have to be used in connection with the Sub-Committee's anti-corrosive problems, such compositions are already available on the market, as the Investigators are well aware, and their use would in no way hamper the Sub-Committee in the continuation of their work on corrosion problems.

It would be grossly unfair, in view of the method of testing adopted, if the Marine Corrosion Sub-Committee's classification of proprietary brands were taken into account by interested parties.

As this country is foremost in the world in anti-fouling compositions, it seems very unnecessary for a committee completely outside the anti-fouling compositions trade to undertake work of this kind and to publish it. In its present form, with its undertone derogatory to the compositions manufacturers, the Report cannot be expected to improve British exports of anti-fouling compositions.

In view of the national importance of the industry, it is hoped that The Iron and Steel Institute will give serious consideration to the criticisms which have been put forward.

Sir Stanley Goodall, K.C.B., C.B., O.B.E. (Assistant Controller (W.P.), Admiralty, London) wrote: The work of the Sub-Committee is of great importance to the Admiralty for reasons which, though commonplace to all those who have to deal with ships, it may be desirable to emphasise.

As the Sub-Committee have shown, fouling and corrosion are interrelated. But the evil effects of the two may be considered separately. Fouling causes a serious reduction in speed, an increase in fuel consumption and consequent loss of endurance. Both speed and endurance are very important warship requirements. Great endurance is essential for British warships, especially in a war such as the present. If fouling is unduly rapid, the time a ship can be out of dry-dock is reduced unless serious loss of speed and endurance are accepted. Such frequent dockings not only absorb labour and time but add to the programme of work to be done in dry-docks. The latter point is of particular importance in war-time, when casualties add to the amount of work that must be done in dry-docks. One result of undue fouling that is not generally appreciated is that when a very foul ship is driven hard and the propeller revolutions are thereby inappropriate to the speed through the water, vibration often becomes severe, which is again a serious matter in warships. When a new warship is designed great pains are taken to obtain the best possible underwater form, to reduce the resistance of appendages, and to gain $\frac{1}{2}\%$ here and $\frac{1}{2}\%$ there, in order to obtain the highest possible speed on the horse power developed. The fruit of such work can be quickly lost if steps are not taken to obtain the best possible means of keeping fouling to a minimum.

Corrosion, though generally not so omnipresent as fouling, has more serious effects, as it not only involves a wastage of steel, another factor that is most important in war-time, but considerable expenditure of labour and time in dock.

From the above it is clear that both from an operational standpoint and from economic considerations it is essential that every means of reducing fouling and wastage caused by corrosion should receive detailed and adequate attention.

In the United States of America work on parallel lines to those followed by the Sub-Committee has been proceeding for a number of years. A short time ago an officer of my Department was in North America, and while there was able to devote a little of his time to discussing with American naval authorities the problems associated with the fouling of ships. He informed me on his return that researches on that side of the Atlantic have led to the belief that the most important aspect of anti-fouling research is the knowledge of the leaching rates of the toxic ingredients of anti-fouling compositions, in particular, the leaching rate of copper. They claim to have established a relationship between the leaching rates and the anti-fouling qualities of the compositions. Since toxic ingredients in anti-fouling compositions are there with a set purpose, it appears eminently reasonable to hold that the rate at which they emerge from the composition is of fundamental importance. I note from the remarks at the top of p. 417 P of the Report that the Sub-Committee have also been investigating leaching rates.

In the past it has been the practice of the Admiralty to judge the relative values of anti-fouling compositions by full-scale ship tests. These take time, and, although eminently practical, are only unimpeachable tests when the various compositions tried are all subjected to the same conditions. If it were definitely established that there is a relationship between leaching rates and anti-fouling qualities, full-scale ship tests might become unnecessary.

In conclusion, I wish to pay a tribute to Dr. Bengough for his leadership, to his collaborators on the Sub-Committee and to all those who assisted in the work. The painstaking and enthusiastic manner in which their researches have been pursued and the excellent way in which their activities are recorded in this Report deserve praise. I trust that the Sub-Committee will continue the good work in the same spirit of energy and enthusiasm. There is still much to be done.

Mr. W. E. Ballard (Metallisation, Ltd., Dudley) wrote: I have read the Report with the greatest of interest and I would like to congratulate all those who have had a share in its compilation. The Report certainly maintains the very high standard that has been set by previous work, and should be of great use as a guide to those interested in this problem of marine corrosion.

It is the First Report of the Sub-Committee, and as such it rightly indicates the complexities of the subject. It would therefore be much easier to formulate a long list of questions which must occur to everyone reading through it than to give any real constructive criticism. My own interests are, of course, largely centred round the use of metallic undercoatings, and from this angle the results give me a good deal of satisfaction, particularly as for many years marine engineers have taken great pains to explain to me the very great excellencies of good oxide paint and the uselessness of any form of metallic coating. It is particularly satisfactory to see in print evidence that sprayed-zinc surfaces do not suffer loss of weight more rapidly than hot-galvanised coatings. The matte surface of zinc-sprayed coatings has given rise to a belief in some quarters that the surface must be more rapidly attacked by corrosive agents than the much smoother hot-galvanised surface. The anti-fouling properties of zinc appear to be much more noticeable than I would have expected, although my own experience has shown that these properties are considerable. Small amounts of zinc have been found to have far-reaching effects on the metabolism of the higher animals, and it is hardly likely that so active an ion would be passive in its action towards lower forms of life.

I think that the behaviour of aluminium-coated specimens deserves some consideration. It is now generally agreed that sprayed-aluminium coatings have fully justified all the claims made for them as a preventive of atmospheric corrosion, but I do not

believe that it should be expected that they would have anti-fouling properties.

The corrosion products of aluminium tend towards basicity, and in immersed conditions remain to some extent colloidal. A good proportion of the earth's crust will, in all probability, give similar products on long contact with sea water and therefore there would appear to be no reason to expect that aluminium would be anything but kind to marine growths. Furthermore, an anti-fouling paint is shown to be of necessity somewhat porous, and the products of solution of the paint may well be absorbed by the colloidal aluminium corrosion products to some extent, and so become inoperative. It should be noted that even in immersed conditions the aluminium has behaved well as a protective measure and this is borne out by practical experience. Aluminium coatings of about 0·004 in. in thickness have protected, for a reasonable time, the blades of cast-iron propellers, but, of course, in this case, marine growths are not very noticeable.

Some remarks are made in the Report on the rust shown by the sherardised samples and this is not surprising, as the experts in this process have not claimed it to be ideal under conditions of immersion. I feel that, in case of misunderstanding, it should be made quite clear that sherardised coatings do give reasonable service under the conditions of exposure and economics for which they are used.

With regard to lead coatings, the excellence of this metal for resisting the attack of aerated sea water is, in my experience, well proved, but its utility from a practical point of view is open to question. The Report stresses the danger of fouling at holidays. Lead coatings in practice are generally found to be very soft and very easily damaged, and comparatively small floating bodies will damage lead coatings applied to ships' plates. Lead coatings would perhaps be an answer to some forms of propeller cavitation if this type of damage could be avoided. I am particularly interested in the evidence that the attachment of marine growth follows break-down and that as yet there is no evidence that these growths cause breakdown. Personally, I have held this view for a long time, but the majority of sea-going engineers appear to think otherwise. Paint manufacturers have always been somewhat prone to make exaggerated claims for their particular brands, and have not been receptive to the idea of metallic undercoats. Nevertheless, I must say that I am surprised at the number of paints which have been classed as inferior by the Investigators. In fairness again, it should be stated that many of the proprietary brands of paint have withstood severe service conditions, and I wonder, therefore, whether the first results are a little more pessimistic than may be justified.

The Report seems to indicate that good results are possible by repainting on top of old paint until a good thick layer is obtained.

My experience indicates that this is often carried out in practice and the thickness of paint layers that can be removed from some vessels is amazing. I have known cases where paint layers have been as thick as the plate, and yet corrosion has not been inhibited and fouling still takes place.

The reason is that this very heavy plastering of paint tends to become brittle and is certainly very laminated. As with lead coatings, damage is caused in places by the ship striking objects in the water. The steel exposed rusts and starts blistering, and extensive damage is often observed. If an undercoating is applied which is really protective, I doubt the wisdom or necessity of repainting to the extent which is indicated.

It would appear that the necessity of the toxic material in the anti-fouling composition being slowly dissolved is indicated. This would appear to demand a porous nature in the anti-fouling composition, which may reduce its strength and cause it to disintegrate. It is possible, by adjustment, to make a metal-spraying pistol give a coating which is porous and somewhat rough. Therefore, if an organic anti-fouling medium can be found, it might be given mechanical strength by covering the normal sprayed layer of zinc, acting as the undercoat, with a layer of porous zinc and then painting with the organic solution, so allowing the anti-fouling composition to enter the pores.

In some quarters there is a prejudice against spraying which applies both to metal and to paint. In all probability this will gradually disappear in post-war years. It should be definitely stated that metal-spraying of a ship's hull presents few practical difficulties, and the results shown in this Report are, therefore, of much more than academic interest. In my opinion, the day is not so far distant when some of the newer synthetic materials will be available as cheap protective coatings, and this possibility is, of course, envisaged by the authors in their preliminary remarks.

I wish the Sub-Committee every success in the continuation of their work.

Mr. A. Nicholls, C.B.E. (formerly at H.M. Dockyard, Devonport), wrote: The work of the Sub-Committee is well known, attacking, as it does, one of the most serious problems confronting the naval architect—corrosion. Although research and experiment have been constant since the introduction of steel to replace the comparatively non-corrosive iron in shipbuilding, the evil persists to an alarming degree.

The writer has just replaced about 40% of the outer bottom of a foreign war vessel, where pitting had caused the limit of safety to be reached in seven years.

This problem is more acute than fouling, and we are still far from a solution. Many and diverse reasons are advanced, but it is a fact that, until the advent of the modern alloyed steels, the

corrosive effect was more or less quiescent, whereas with modern steel pitting breaks forth like a rash, and causes serious loss of strength, even before the ship is in commission.

The research carried out by the Sub-Committee's investigators is very thorough; nothing seems to have escaped their scrutiny, unless it is the supposed organic constituents in some proprietary paints.

It is, perhaps, well known that the Admiralty have, for many years, carried out tests on protective and anti-fouling compositions. The general constituents of all approved makers are known and tabulated. Instead of small samples tested on rafts, full-scale trials have been carried out with vessels plying in different waters.

Home experiments may carry us a certain distance, but the rapidity of fouling varies with the locality, as is well known. Vessels may arrive at one port badly fouled, and by lying in a fresh water berth, generally in a river, may resume their journey fairly clear of marine growth.

The Admiralty method of testing compositions by "quartering," *i.e.*, painting opposite ends of the vessel with competing compositions, gives a fair comparison in regard to wear and resistance.

The classification of the various compositions does not appear to include what are known as grease paints, which have great exfoliating properties, and have proved successful in preservation both from corrosion and from fouling, but the weight and resistance per square foot are features which have to be taken into consideration when their use is proposed.

The Sub-Committee have a large field still in front of them and one wishes them success in their efforts.

Mr. S. Payne (H.M. Dockyard, Devonport) contributed the following remarks:

Page 368 P.—It is agreed that the conditions to which raft specimens were exposed are more stringent than life under service. If the average failure by fouling of specimens was 22·6 weeks and a factor of 2 or 3 is applied as recommended, the failure under service conditions should not occur on an average under 45 weeks. My experience has been that failure almost invariably occurs in much less than this period. Hence the desire of most firms with an interest in fuel economy and of the Admiralty with its interest in maximum speed to have six-monthly dockings where possible. It is really a matter of what is meant by "failure by fouling." My interpretation is: When there is clear evidence in dry-dock that a great part of the anti-fouling composition has disappeared and some fouling has started.

Page 382 P, *Pickled Specimens*.—It may be of interest to note that experiments at Devonport recently on the best strength for pickling confirm the value of the standard Admiralty procedure of

5% by volume of hydrochloric acid. Less than this amount made pickling far too slow, and when appreciably stronger solutions were used the results were occasionally patchy. A hydrometer is regularly used to keep the solution in the bath at the right strength.

It is hoped that the discussion will bring out some practical opinions on the value of pickling. This has been Admiralty practice for many years, and we know from the discussion on the paper of Dr. Bengough and Mr. Shepheard at the recent meeting of the Institution of Naval Architects [1] that American practice now is either to pickle the plates when received at the yard or to apply a plain descaling process.

It is understood that pickling is not common British practice in merchant ships and some of the yards now building ships do not possess pickling baths big enough to make large-scale pickling general. How do the non-pickled plates compare to the others in ships?

A MARINE SUPERINTENDENT wrote: We have frequently been in doubt as to whether it is advantageous to apply anti-corrosive composition to the underwater hulls of ships of some age which have a substantial coating of previously applied composition. Many of our technical staff consider that anti-corrosive composition is of no value unless it can be applied to the bare or nearly bare steel. Others contend that it is advantageous to apply anti-corrosive even if it is not in contact with the bare steel, on the grounds that it gives body to the anti-fouling. For many years ships of the writer's Line which were found well coated have been given only a touch-up of anti-corrosive and a full coat of anti-fouling. During the last three or four years we have been giving a full coat of both anti-corrosive and anti-fouling, whether the surfaces were well covered or not. Up to the present I have not observed any beneficial result through the application of the full coat of anti-corrosive in the case of ships which already had a substantial coating of previously applied composition.

Mr. N. E. ROBSON (Messrs. Atkinson, Young and Robson, Newcastle-on-Tyne) wrote: To an owner of petroleum-spirit-carrying tankers the marine corrosion, dealt with in the Report, is a minor trouble compared with the corrosion of the steel bulkheads, brackets, stiffening, &c., in the cargo tanks, which often becomes serious before the ship is ten years old, and at the second No. 1 survey, when the ship is sixteen years old, if not before, is the cause which makes it necessary for very extensive renewals to be carried out, or the ship to be condemned and sold to the shipbreakers for demolition. In corrosion of this nature, which is not dealt with in the Report, there is an extensive field awaiting research

[1] G. D. Bengough and V. G. Shepheard, "The Corrosion and Fouling of Ships," Institution of Naval Architects, Apr. 15, 1943.

in the laboratory and on board ship on similar lines to that carried out in connection with marine corrosion.

Rear-Admiral H. P. Boxer (retd.) (Detel Products, Ltd., Greenford, Middlesex) wrote: The raft tests have been of great interest to me, particularly so because they have proved the necessity for the use of the best obtainable anti-corrosive coatings as the primer coat on ships' hulls. They have singled out the best anti-corrosive compositions and have gone a long way towards the solution of the anti-fouling problem.

It seems to me now to be necessary to find suitable anti-fouling compositions which will not only prevent the growth of fouling over a longer period and with a greater killing range but will satisfactorily combine with the anti-corrosive coating to be used. It would appear that there is some necessity for the makers of the two very different coatings to work together if success is to be achieved.

While realising that raft tests are necessary to obtain comparative results of various coatings under similar conditions of exposure, I am of the strong opinion that they should be supplemented by large-scale practical tests on ships' hulls under seagoing conditions, as there are elements other than marine growth, such as electrolytic action, which will destroy the coatings and produce rapid deterioration of the plating and rivets.

In conclusion, I suggest that mechanical methods must be devised in the near future for scraping, cleaning and coating ships' hulls, and the docks so adapted to enable these methods to be carried out. Also, when practicable, ships should steam through the fresher water of river estuaries to reduce any accumulation of fouling.

SUB-COMMITTEE'S REPLY.

The Marine Corrosion Sub-Committee wrote in reply: It will be advisable to consider the communication from the Association of Ships' Compositions Manufacturers first, since this constitutes the most important criticism of the Sub-Committee's work. The criticism falls under two broad heads: (*a*) Policy, and (*b*) the experimental procedure adopted by the Sub-Committee.

As regards policy, it is readily agreed that one of the major aims of organised scientific research should be to promote the welfare and efficiency of industry generally; consequently, any attempt to expose an industry to unmerited criticism is most undesirable in a scientific publication. This is not the object of those comments in the Report to which the Association take exception. They are believed to be a fair statement of fact and are adduced as reasons for the initiation and continued conduct of this investigation, which

the Sub-Committee hold to be both necessary and desirable in the interests of the users of ships' compositions.

Whilst it is not contested that considerable research has been and is being conducted in the laboratories of individual composition manufacturers, it is difficult to form any conclusion as to how far this is generally true of the industry. It is certain—and this is the crux of the difference in the attitudes of the Sub-Committee and of the Association—that little, if any, of this research work has been published. Indeed, since the formation of the Association of Ships' Compositions Manufacturers is a most recent event, occurring after the initiation of the Sub-Committee's researches, it is improbable that there has been any marked interchange of scientific information within the industry itself. In the Sub-Committee's view such a state of affairs is inimical to progress and in the long run is not even in the interest of composition manufacturers themselves, since research work of any kind fails to bear its maximum fruit until it has been published and discussed. The number of publications dealing with protective and anti-fouling compositions in British scientific literature is meagre, and it is fair to claim that the Sub-Committee's First Report represents the first published organised attempt by investigators with no financial interest in the subject to deal with it on a broad and adequate scientific basis.

The Sub-Committee regret that the Association should have charged them with withholding acknowledgments to "those firms in the anti-fouling composition industry who laid open their research laboratories and testing stations to the Sub-Committee" at the time when the Sub-Committee were initiating their researches. The fact is that only one such testing station belonging to one firm was visited by representatives of the Sub-Committee. This visit occurred on December 8th, 1939, when the Chairman, the Official Investigator and one other Member accompanied representatives of the Admiralty Corrosion Committee on a visit to the marine station of the International Paint and Compositions Co., Ltd., at Newton Ferrars. The party was cordially received by members of the scientific staff of the International Company and an inspection of the laboratory and testing raft was made. It is possible that, writing three years after the event, the Association of Ships' Compositions Manufacturers may be under the impression that the Sub-Committee's testing procedure was markedly influenced by this visit. The Sub-Committee can only assure the Association that this was not the case, since their experimental arrangements had already been made in detail and were not appreciably modified thereafter. Consequently, whilst the Sub-Committee gladly express their appreciation of the courtesy shown by the International Paint Company on that occasion, they cannot agree that their policy or subsequent action were in any tangible way affected by this visit, or that they have been materially assisted in the conduct of their investigations by the Association. There have been occasional

contacts between the Sub-Committee's biologists and those of the International Paint Company; it is hoped that these will continue.

The main criticism of the experimental work adduced by the Association relates to the raft tests on proprietary compositions. It is chiefly centred round the fact that no attempt was made to control the weights of the individual paint films applied. Two courses were open to the Sub-Committee:

(1) To endeavour to apply the wide variety of compositions represented at a uniform predetermined spreading rate, or

(2) To apply the compositions as they stood, brushing them out so as to give as adequate a coating as possible in each case.

As regards (1), it should be noted that the weights per gallon of the anti-corrosive compositions in the Caernarvon tests varied from 10·2 to 39·9 lb. In the case of those paints for which the necessary data are available, it is calculated that the density of the dry film varied from about 1·25 to 5·65. Presumably, similar variations occurred for the anti-fouling compositions. It is clear that the application of equal weights of paint per unit area would have resulted in substantial differences in film thickness. Scientifically it would be more correct to endeavour to apply the paints in the same film thickness or alternatively at the same spreading rate per gallon. In the Sub-Committee's tests, the variation in the consistency of the individual compositions was such that it would have been impossible to adopt either course, unless the heavier compositions and those with the greater body had been brushed out to an excessive thinness, so as to match the more fluid paints; the latter would have dripped from the specimens like water had attempts been made to apply them in appreciably greater weights per unit area.

For a practical test such as that contemplated, procedure (2) seemed far more sensible and was adopted. In effect, do the Association seriously suggest that if, instead of the small samples sent for the Sub-Committee's tests, substantial quantities of the same compositions had been supplied by each firm, and each composition had been applied to a different ship, the foreman painters concerned would have followed any other course? Apart from a possible thinning of the thickest compositions, they would have applied them all as received and would certainly have made no attempt to ensure that each and every paint was applied at the same uniform and predetermined spreading rate.

With reference to Table IV., the Association point out that the maximum variation in the weight of individual painting schemes was 5·4 to 1 at Plymouth and 4·6 to 1 at Caernarvon and go on to state that anything less scientific or more inaccurate

would be difficult to imagine. The reply to this criticism is the simple statement of fact that similar variations in weights of paint would have occurred if the tests had been carried out under practical conditions on a ship's hull. In the published account of the tests conducted by the Main Committee on the hull of H.M.S. *Basset* will be found a record of observations of the weights of paint applied at successive dry-dockings.[1] These show that the mean weight of eight anti-corrosive coats applied over a period of two years was 0·51 oz. of wet paint per sq. ft. The corresponding figure for five coats of anti-fouling composition was 0·53 oz. per sq. ft. The variation in the weight of individual anti-corrosive coats was from 0·31 to 1·2 oz. per sq. ft. and in that of the anti-fouling coats from 0·27 to 0·8 oz. per sq. ft.[2] When it is considered that all the compositions concerned were obtained from only two different manufacturers and that the painting was carried out under good conditions in H.M. dockyards it is obvious that an overall variation of 5 to 1 under practical conditions might readily occur if a test were made on between twenty and thirty brands of proprietary paints.

It should further be noted that the average weight of a three-coat painting system as actually applied to the hull of H.M.S. *Basset*, *i.e.*, two anti-corrosive and one anti-fouling coat, was 1·55 oz. of wet paint per sq. ft. The average figures for the compositions in the Caernarvon tests are given below :

Weight of Wet Paint. Oz. per sq. ft.

Coat.	Pickled Surface.	Repainted Surface.
First, anti-corrosive	0·219	0·248
Second, anti-corrosive	0·222	0·240
Third, anti-fouling	0·346	0·365
	0·787	0·853

It will be seen that the total weight of paint is significantly greater on a repainted than on a pickled surface. The average figure for both surfaces is 0·82 oz. per sq. ft. as compared with the figure of 1·55 oz. per sq. ft. for the practical test on H.M.S. *Basset*. It is fair to state that rather more paint will be lost under practical conditions than in the case of small specimens and, further, that some of it will be used to fill up depressions in the old paint surface. Consequently, the difference in the thickness of the coatings applied to the small specimens and of compositions as applied to a ship's hull, though real, should not be exaggerated. In all probability

[1] *Cf.* Fifth Report of the Corrosion Committee, p. 205, Table CXXI., *The Iron and Steel Institute*, 1938, *Special Report No.* 21.

[2] The heaviest coatings were recorded at a dry-docking in May and the lightest at one in December, so that any temperature effect would have tended to reduce the differences between them.

the films on the specimens were at least half as thick as those applied to ships' hulls and may have been more uniform. It is suggested that the soundest procedure when comparing a number of different compositions would be to apply each at two or three different spreading rates, but this course would have been impracticable in the case of an already extensive investigation such as that under discussion.

The question of film thickness is closely associated with the Sub-Committee's remarks concerning consistency, to which the Association take exception. There was a wide variation in the consistency of the samples received from individual manufacturers, and the Association cannot possibly maintain the position that such a wide variation in consistency is desirable. The manufacturers who supplied the compositions with the thinnest consistencies probably obtained less favourable results than they would have done if they had paid attention to this factor. They may, of course, argue that the samples submitted were formulated for application by long-handled strikers, such as would be used under practical conditions. Although this explanation might hold good for the first set of samples tested at Plymouth, it cannot be adduced in respect of the second set of samples, supplied for Caernarvon, where marked differences in consistency were again observed, since at the conclusion of the Plymouth tests a detailed report on the conduct of the experiments and the behaviour of their own compositions was sent to each individual manufacturer; consequently, they should have been under no illusion as to the experimental procedure to be adopted in the raft rests at Caernarvon.

With reference to the Association's suggestion that "the prevention of corrosion seems to be more of a problem for the metallurgist to produce steel less subject to corrosion," it may be remarked that the Corrosion Committee have been busily engaged for a number of years in investigating the effects of alloying elements on the corrosion resistance of steel in various types of corrosive media, including sea water. In fact, they have recently prepared a further series of some 50 laboratory heats of special steels for this purpose. The general trend of the observations made to date is that, in the absence of any revolutionary discovery, it will remain necessary to protect any steels of the lightly-alloyed type such as might be suitable on economic grounds for use for shipbuilding purposes. Consequently, the study of protective coatings for steel immersed in sea water is a vital problem; at present, the most important of such coatings is paint. The bearing of the behaviour of the anti-corrosive coat on that of the anti-fouling composition has already been stressed in the Report and need not be elaborated here.

It does not necessarily follow that the publication of reliable formulations for bottom compositions would automatically bar the way to further development and research by individual manu-

facturers. The policy pursued by the German State Railways has much to commend it. Whilst specifying formulations and performance tests for the paints required for their various maintenance purposes, they are prepared to consider alternative products from paint manufacturers, provided that the latter demonstrate to the Railway Company's satisfaction that these are better than their existing formulations.[1]

With reference to the summary of the analyses of proprietary compositions given in Tables II. and III., it is readily conceded that a differentiation between anti-corrosive and anti-fouling compositions would have been desirable on scientific grounds. The main purpose of these Tables is, however, to demonstrate the wide range of formulations used for bottom compositions at present. They cannot all be right; some must be better than others, and the Sub-Committee reiterate their remark that it is desirable to reduce ships' bottom compositions to a few tested formulations of known performance, incorporating the best combinations of medium, pigment and toxins, provided that, as already stated, this is done in such a way as not to bar the door to further progress.

In no passage, so far as can be judged, does the Official Investigator "make it clear" that these analyses will help to formulate compositions with the avowed intention of publication. Their main object was to obtain general information about the materials tested. The analyses have yielded one or two interesting indications, but broadly it is fair to state that the Sub-Committee are proceeding to build up their own formulations from first principles, with no reference whatever to existing proprietary materials.

The answer to the enquiry as to what significance is to be attached to the testing method in which an unpainted holiday is left on the surface is that the ideal paint is one that will give adequate protection to the rest of the plate and at the same time prevent severe corrosion in the holiday, *i.e.*, the test is intended as a criterion whether a given paint will or will not stimulate corrosion by electrolytic action at a bare patch such as might be caused, for instance, by mechanical damage. Both the paints postulated by the Association would be considered imperfect.

With reference to the Association's remarks on Table VIII., there has been no general condemnation of commercial anti-fouling compositions. What has been established is that some of them when applied to new construction are much better than others. The standards of performance at which compositions should be graded as good or bad, &c., must be chosen in an arbitrary manner and will depend on the circumstances of the test. The Sub-Committee have been at pains throughout the Report to emphasise the differences between their raft tests and practical conditions. They make it clear that a different order of merit and improved

[1] Deutsche Reichsbahn-Gesellschaft, "Technische Vorschriften für den Rostschutz von Stahlbauwerken," 1935, paragraph 1, clause 9.

performance from the bad compositions might be observed after the paint film has built up to a considerable thickness on the hull of the vessel. Yet, when all these remarks and qualifications have been made, the fact remains that the policy of applying an inferior paint sufficiently often until it sticks does not seem to be the best, and there is no doubt that by the use of better compositions the desired performance could be achieved at an earlier stage in the ship's history with the application of fewer coats of composition.

The Sub-Committee agree that further evidence is desirable to confirm their statement that a toxic index of 30 or more is necessary to ensure a life of six months against fouling at Caernarvon. This subject and the Association's comments on the comparison of the result of raft tests with service performance are considered in detail later in this reply.

The Sub-Committee also agree that no deductions of value can be made from Table XI. and in fact they have contented themselves with placing the results on record and making no deductions. Incidentally, the necessity for such data is an illustration of the complete lack of published data in the scientific literature. The effect of the interval between the application of the anti-fouling coat and immersion is amenable to simple physico-chemical study.

It would have been more correct to state at the foot of p. 371 P that a few of the paint films had lost their adhesion during immersion; that they were readily removed by cleaning, rather than the fact that they had softened, was taken as an indication that they were nearing the end of their useful life.

It is regretted that with reference to Table XIII. it is not made clear in the text that the same specimens were used at Plymouth and Caernarvon for each proprietary paint (with the proviso that, there being more compositions at Caernarvon than at Plymouth, it was necessary to prepare an additional number of dummy specimens, as described on p. 357 P). Consequently, in the majority of cases, the old and the new paints were the same painting scheme.

The Sub-Committee agree that the deposit of calcium carbonate referred to on p. 401 P forms the cathode. Actually, the deposit contains rather more magnesium than calcium. This is shown by the analysis of a deposit produced electrolytically on steel cathodes in sea water in the course of some experiments undertaken by the Corrosion Committee to elucidate the causes of a severe attack of pitting on the shell plates of H.M.S. *Niger*.[1]

In replying to the other contributors to the discussion, the Sub-Committee wish first of all to thank Sir Stanley Goodall, Mr. Ballard and Mr. Nicholls for their kind and encouraging remarks. They hope that the continued progress of their researches will throw further light on the problems of the prevention both of

[1] Fifth Report of the Corrosion Committee, *loc. cit.*, p. 218.

fouling and of corrosion of ships' hulls and alleviate some of the difficulties to which Sir Stanley Goodall refers.

It will be convenient to deal first with the general questions raised concerning the anti-fouling work and to consider these in the order in which they arise in the Report.

Comparison of Raft with Service Tests.—The Sub-Committee are now carrying out tests of both types. While it would appear that ship tests are more useful from the practical point of view, this is not necessarily true. Fouling is a very discontinuous process—non-poisonous plates can often be immersed for some days during the "fouling season" and yet collect only a negligible amount of young organisms. It is clear that a ship which voyages from port to port, with limited periods of stay in each, may quite possibly escape fouling completely even though its anti-fouling coating is ineffective. If the ship is quartered with two different compositions, a comparison of the performance of the two will, as Mr. Nicholls points out, provide reliable comparative evidence of the wear and resistance of the two paints. Complete absence of fouling in such a test does not indicate that both paints are good from the anti-fouling point of view, and even if one paint is fouled and the other free from fouling the comparison does not necessarily prove that the unfouled paint is the superior. This sounds surprising, but a concrete example can be provided from a carefully controlled raft test at Millport where, of two paints, after six months the better paint showed hydroid fouling and the inferior one no fouling.

Only when the number of service tests is very considerable, or when the vessel has been in port for a very large proportion of the time, can a ship test be regarded as fully conclusive. For the testing of new compositions it therefore follows that a raft test is not only simplest but much more decisive.

From the biological point of view the stringency of a raft test lies merely in the fact that it provides a continuous long exposure to a heavy though intermittent source of infection; a paint failure will be detected within a short time of its occurrence on a raft test; it may escape serious fouling for a very long period on a single ship test.

In this connection Mr. Payne's remarks are of much interest, since they would indicate that the discrepancy between the lives of paints on the raft and in a large number of service tests is smaller than the Sub-Committee's Report suggests.

Exfoliation Mechanisms.—The use of grease paints, mentioned by Mr. Nicholls, seems to be limited to services where frequent replacement of the coating is possible. The mechanism of protection in these paints necessarily involves the erosion of the paint, which cannot have a long life. In addition, such paints would be difficult to design to work over very wide *ranges* of temperature.

Mr. Dyche Teague's reference to the lack of fouling on algal surfaces is probably a biological example of an exfoliation mechanism,

due to a continuous secretion of slime from the surface. Dead algæ and living marine organisms possessing a " dead " skin—such as crabs and lobsters—do foul quite freely. The Americans have reported that algal decoctions have a definite anti-fouling action, but in the latest reference to this subject [1] the decoction was stated to be so violently corrosive that paint tests with it were impracticable.

Removal of Fouling Organisms.—It is known that the friction of water movement against the ship's side removes a considerable amount of the algal and hydroid fouling. This process may be aided by first killing the organisms in fresh water, in the manner referred to by Rear-Admiral Boxer. This will kill some, though not all, of the algal fouling (some species of *Cladophora* and *Enteromorpha* can survive in fresh water) and will kill most of the animal fouling, whose skeletons and shells will remain attached. Such a procedure will therefore be advantageous if carried out soon after the settlement of the organisms, but will have much less effect on fouling which is well advanced.

Toxic Index.—The use of the " toxic index " concept to predict the life of the paint does not fully represent the facts, as the Association of Ships' Compositions Manufacturers point out; it was originally developed for a different purpose, for which it is much better employed, *i.e.*, to predict the order of merit as regards protection against fouling afforded by a series of paints at any given time. The index was based on a statistical analysis (made by the multiple-correlation technique) of the performance of all the paints tested, at two and six months after immersion, compared with the copper, mercury and arsenic contents given by analysis and with the weight of paint applied. It was found possible to predict with surprising accuracy the anti-fouling effect of twenty-four out of thirty-one of the compositions from these four values alone. Four paints which gave better results than predicted revealed on analysis the presence of an organic arsenical derivative of diphenylamine; one paint was a very abnormal type of coating not comparable with the others.

The fact that the performance—not the *life*—was predicted within the small limits of experimental error in twenty-four cases out of the remaining twenty-six suggests very strongly that only the copper, mercury (and to a very small extent the arsenic) contents appear to play a part in the behaviour of the compositions. The exceptions, in which the presence of the organic arsenical (not found in twenty-seven paints) was independently established by analysis, serve to emphasise rather than to disprove the rule.

The correlation between the weight of paint coat and the anti-fouling effect in this analysis was negative, *i.e.*, the greater the weight of paint (other things being equal) the less was the anti-fouling effect. This is in agreement with the comments of the Association that low weights are associated with more rapid breakdown (*i.e.*, more rapid liberation of the poisons and therefore greater toxicity).

[1] Adamson, *Drugs, Oils and Paints*, 1934, vol. 49, p. 454.

It is not intended to suggest that the percentage of poisons is the only factor concerned in the behaviour of an anti-fouling paint, as the results in Section C clearly indicate. The success of the toxic index concept does, however, imply that the paint vehicles used by all the composition manufacturers are sufficiently similar in character for the anti-fouling effect to be predicted almost entirely from the copper and mercury contents of the paint.

Poisons in Anti-Fouling Paints.—While all the evidence of the Sub-Committee suggests that inorganic arsenic (*e.g.*, in the form of As_2O_3, arsenites, aceto-arsenites) has no anti-fouling property, organic arsenic may be quite effective. The use of the "poison gas," chlorphenarsazine (D.M.) as an anti-fouling agent is well known; this substance is at least 100 times as toxic as sodium arsenite to marine crustacea.

The use of leaching tests in evaluating the efficacy of copper-containing paints has been known to the trade for some time, perhaps even before the American work referred to by Sir Stanley Goodall. It is hoped to describe in some detail the technique and results of leaching tests for copper, mercury and a number of organic poisons in the next Report of the Sub-Committee.

The Sub-Committee's work would suggest that the acid radical with which copper is combined does not influence the anti-fouling efficiency of the paint, provided that the copper compound used is not too soluble (leading to premature breakdown) or too insoluble (which gives no anti-fouling action). For inorganic compounds, therefore, cuprous oxide (with the highest copper content and the right order of solubility) is likely to be the most effective. Copper bronze may be more so than cuprous oxide, but it raises special problems, *e.g.*, of electrolytic action, &c.

The fact that some organic poisons are used in commercial paints (in Great Britain and elsewhere) is well known. Nevertheless, it is evident that further investigation along these lines is needed, since a very large amount of mercury is still used in Britain in spite of the supply position.

It is very doubtful whether zinc can have a practical anti-fouling value. Judging from its toxicity, it could only function by so rapid a rate of solution that an impossibly large reservoir of zinc would have to be provided to maintain its toxicity for any length of time. Mr. Ballard's suggestion to use the porous structure of certain types of zinc-sprayed coatings as a matrix to contain the poisons is an interesting one. Some work on these lines is already being carried out by the Sub-Committee.

Paint Breakdown.—If the discharge rate of the poison is sufficiently reduced, failure of the paint system to prevent fouling may occur before the disappearance of the anti-fouling coat. On the other hand the Sub-Committee would agree with Mr. Payne that failure has occurred when *any* appreciable amount of fouling has set in.

The statement on p. 418 P that some paints fail by an almost

catastrophic mechanical breakdown is based on leaching tests in which the anti-fouling coating was applied at a constant spreading rate of 0·52 oz. per sq. ft. (wet weight).

While it is agreed that flaking is found to be less on ships in service than on the test plates used in the present work, shipbuilders are almost unanimous in pointing out the loss by flaking of a considerable area of the painting system applied before launching. In view of the amount of new shipping now being produced and the absence of dry-docking facilities to repaint it after the fitting-out period, this defect may be of greatly increased importance at present.

Table XXXII. and Fig. 10 refer to bacterial slime formation. Fig. 12 refers to slime which is largely diatomaceous in character.

In conclusion, answers are given to a few individual questions not covered by the previous general replies.

The oral discussion chiefly centred round the question raised by Dr. Hatfield as to whether there has been any change in the composition of the surface characteristics of ships' plates as supplied by steelworks during the past 40 years that would affect their resistance to corrosion in sea water. This and other cognate points were dealt with at the time by Mr. Kerr, Mr. Harbord, Mr. Robinson and Mr. Ripley, and the Sub-Committee are in substantial agreement with the views expressed by these gentlemen. Thus, as Mr. Harbord stated, it is true that, owing to the continued use of scrap, the amount of elements such as copper and chromium in ordinary mild steel are increasing. It may be remarked, however, that considerable tonnages are still produced in Lincolnshire and elsewhere from practically virgin pig iron with a low copper content. So far as the presence of copper is concerned, the atmospheric corrosion tests of the main Committee failed to show any significant differences in the times necessary to remove the rolling scale by weathering from ordinary and from copper-bearing steel (copper up to 0·5%) in different climates.

As Mr. Robinson remarked, rolling conditions have altered considerably during recent years. On the whole, since finishing temperatures will in general be higher, this should lead to more rapid and complete removal of mill scale by weathering; the redder low-temperature scales are more resistant. Complete removal of the mill scale by weathering takes considerable time and cannot be guaranteed to occur under much less than a year in the climate of Britain; consequently, the quicker delivery and use of plates under modern conditions will lead to less complete descaling as compared with older days.

Mr. Kerr's enquiry as to whether a type of steel or steel surface could be produced which would render painting unnecessary has already been considered when replying to the Association of Ships' Compositions Manufacturers. In the present state of knowledge an economic solution on these lines appears improbable.

In reply to Mr. Wood, it is correct that arsenic has anti-corrosive properties. For instance, the presence of a small percentage of arsenic in steel, say, 0·1%, will increase its resistance to atmospheric corrosion. It is an interesting speculation as to whether the incorporation of poisons, so far as practicable, in the anti-corrosive coats themselves would enhance the behaviour of the anti-fouling composition proper.

Mr. Ballard's comments on the use of metallic coatings for underwater protection are particularly welcome. He refers to the possible use of sprayed lead coatings, but expresses doubt as to their suitability on mechanical grounds. A variety of metal-sprayed specimens was prepared for test by the Protective Coatings Sub-Committee shortly before the outbreak of war. Some of these have been exposed in sea water for two years and examined after removal. It is permissible to anticipate publication to the extent of saying that Mr. Ballard's doubts are correct. It was found that coatings both of lead and of tin had failed locally and that intense corrosion of the steel base had occurred at these places as a result of galvanic action, the coatings being cathodic to the steel.

The practical contribution from a Marine Superintendent is interesting. It seems reasonable that if the paint film is intact the application of further anti-corrosive paint might prove unnecessary. Presumably the formulation of the anti-fouling composition would require modification if it were applied directly to the old paint with no intervening anti-corrosive coat. It is probably correct to conclude that there is little point in applying an inhibitive paint unless it is in direct contact with the steel or the existing paint film is imperfect. For instance, in the case of protection against atmospheric corrosion, the priming paint might suitably be of red lead, which is inhibitive, but it is unnecessary to use this pigment in the finishing coats, quite apart from any considerations of its effects on the physical and chemical properties of the paint film itself. The Sub-Committee would welcome similar practical contributions summarising the experience of other marine superintendents.

The corrosion of the internal plates and fittings of oil tankers is admittedly a serious problem, references to which will be found in the Committee's Fifth Report [1] and in their Fourth Report.[2] Plans for the conduct of experimental work on the subject have been interrupted by the war.

The Sub-Committee are in complete agreement with Rear-Admiral Boxer as to the desirability of introducing mechanical methods of cleaning and coating into dockyards, so far as is practicable. Admittedly, there are grave practical difficulties to be overcome, but these should not prove insuperable. Since success with painting largely depends on the condition of the surface to which it is applied, a fairly substantial expenditure in this direction might prove economical in the long run.

[1] *Loc. cit.*, p. 220.

[2] *The Iron and Steel Institute*, 1936, *Special Report No.* 13, p. 148.

Further Correspondence on

THE FORMATION OF HAIR-LINE CRACKS.—PARTS I. AND II.

By Professor J. H. ANDREW, D.Sc., A. K. BOSE, B.Met., Ph.D., G. A. GEACH, M.Sc., Ph.D., H. LEE, B.Eng., Ph.D., and A. G. QUARRELL, Ph.D., F.Inst.P. (The University of Sheffield).

The two papers bearing the above title were presented for discussion at a Joint Meeting of the Sheffield Society of Engineers and Metallurgists, the Sheffield Metallurgical Association and The Iron and Steel Institute, held at the Royal Victoria Station Hotel, Sheffield, on 24th October, 1942, under the Chairmanship of Dr. W. H. Hatfield, F.R.S. (Vice-President of The Iron and Steel Institute and President of the Sheffield Society of Engineers and Metallurgists). The following contribution was received too late to be included with the rest of the discussion and correspondence, which together with the papers themselves will be found in the *Journal of The Iron and Steel Institute*, 1942, No. II., p. 193 P *et seq.*

(Figs. H to J. = Plate XVIII.)

Mr. A. C. Harris (Steel Corporation of Bengal, Burnpur, Bengal, India) wrote : The following notes are compiled with a view to seeing to what extent industrial exerience with hair-line cracks in basic open-hearth steels can be explained by the conclusions arrived at in the papers and how in some cases there appears to be some contradiction.

(1) *Nature of the Defect.*—The most infallible way of discovering hair-line cracks is by nicking and cold-breaking a bar, when they appear as small grey fibrous lipped " fissures," disposed in the same manner as that brought out by magnetic testing or deep etching, such as shown in Part II., Fig. 35, of the authors' papers. The accompanying photograph, Fig. H, is of a $3\frac{1}{4}$-in. dia. bar broken in this way, and the phenomenon was once aptly described by an operative as " pepper-box piping." Actually the term " hair-line cracks " gives an impression of something almost one-dimensional whereas they are more nearly two-dimensional, the third dimension being so small that only the finest microscopical technique can discover any crack in commercial specimens known to contain them. However, for brevity in what follows, the term " cracks " refers only to the type of defect under discussion.

(2) *Cause.*—The papers having shown that hydrogen is the fundamental cause of these cracks, why was it necessary to soak for so long and quench in order to be sure of obtaining cracks ? In industry the difficulty is to prevent them in certain classes of steels and yet how can, say, 50 or 100 tons of steel absorb anything like an amount of hydrogen comparable to that employed in the experi-

ments? Has any attempt been made to find the minimum absorption of hydrogen required to produce cracks in any one steel—or, say, the minimum time of soaking?

(3) *Prevention and Cure.*—I do not think that I am giving away any trade secrets when I say that cracks may always be prevented by sufficiently slow cooling after hot-working or, if this has not been done, eliminated by further hot-working followed by slow cooling.

Now, this means (*a*) that slow cooling prevents the formation of the hydrogen-rich constituent, or (*b*) that sufficient hydrogen escapes from the steel to render it immune.

Have these factors been determined experimentally, even as to how much hydrogen was evolved on cooling? It would seem that (*b*) is the more potent factor, because steel, once slow-cooled as described, hardly ever shows any cracks in subsequent working. On the other hand, how did hydrogen escape from the large samples slowly cooled and enclosed in hydrogen, as described on p. 233 P of Part II? In the next experiment saturation in hydrogen followed by air-cooling surprisingly did not produce perceptible cracks in as-cast *S*11 steel but did so in hot-rolled specimens. The explanation may have been supplied to some extent in Part I., pp. 200 P–201 P, when discussing as-cast specimens.

If, however, these facts are correlated, then all industry need do is to allow all steel ingots of types known to be prone to cracks to cool before reheating for rolling, a procedure directly opposed to normal practice.

Again, the experiments show the large evolution of hydrogen on cracking and reheating, but if "cracked steel" is reheated, hot-worked and *not* slow-cooled, cracks reappear and continue to do so on further similar treatment. Can methane retention fully account for this? Does the methane also come out in the *one* slow cooling after hot-working that is the complete prevention and cure?

(4) *Effect of Alloys.*—Commercially, trouble is rarely experienced with plain carbon steels on normal cooling, but only with such low-alloy steels as may be made in the basic open-hearth furnace. Of these alloys, increased silicon and chromium (which raise the change point) do not usually give "hydrogen" cracks, but nickel and molybdenum do. Further, a 5% nickel steel gives more trouble than a 3% and a 3% more than a 1% steel. In other words, as mentioned in the paper, a depression of the change point seems to be the crucial factor in the retention of hydrogen or the formation of the "hydrogen-rich constituent." Can the latter be some compound of nickel and hydrogen? It should be remembered that practically all commercial plain carbon steels nowadays contain small but maybe significant percentages of nickel, so that the ability to produce cracks in these does not invalidate the idea (or manganese might substitute for nickel—*see* paragraph (5) below).

FIG. H.—$3\frac{1}{4}$ in. dia. Bar of S11 Steel, nicked and broken. × 0·6.

FIG. I.—Rail Failure in Service due to extension from a grey spot. × 0·6.

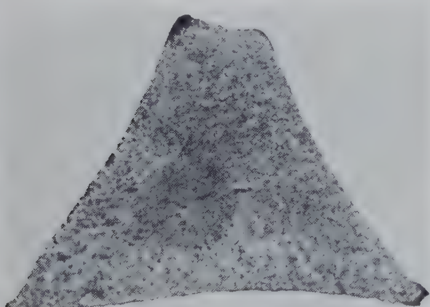


FIG. J.—0·65% Carbon Billet with grey spot after quenching. × 0·8.

[*Harris on Andrew and Others.*

[*To face p.* 454 P.

(5) *Effect of Rapid Cooling on Carbon Steel.*—As mentioned before, hair-line cracks are rarely encountered in the general run of commercial carbon steels. Rails, however, as is well known, sometimes give rise to fissures which can be detected magnetically and which present closely allied features. When a rail head is partially quenched after hot-rolling, as in the sorbitic process, it is apt to develop this defect in a more striking form, giving the once well-known "grey spots," an example of which is shown in Fig. I. Here, again, we have the two-dimensional property and unsymmetrical position well removed from the surface. These spots are so brittle that a rail will fly off at that point even when given a blow some distance away from it. Lest it be thought that it is purely a question of uneven cross-section, Fig. J shows a grey spot in the corner of a 4-in. billet (about 0·65% carbon) which flew off in a conchoidal fracture on water-quenching after rolling. Are these fissures and grey spots also due to hydrogen? The answer may again be found in the cure. If the rails are slowly cooled after sorbitising grey spots are never found, while almost the world over rail-makers have adopted the precaution of controlled cooling even for ordinary rails. Further, this measure has been found more advisable since the increased popularity of higher-manganese content—again that depression of the change point.

(6) *Effect of the Defects on Mechanical Properties.*—The embrittling effect on a rail has already been touched upon. In Table A are quoted figures of tensile tests on two bars of the same cast, one of which was sound and one badly fissured. Yes! it is quite possible

TABLE A.—*Mechanical Test Results.*

Analysis:	C. %.	Si. %.	S. %.	P. %.	Mn. %.	Ni. %.	Cr. %.
	0·30	0·178	0·022	0·024	0·56	3·0	0·39

	Yield Point. Tons per sq. in.	Max. Stress. Tons per sq. in.	Elongation. %.	Reduction of Area. %.
Good bar, O.Q. 850° C., T. 600° C. . . .	42·0	60·0	22·0	62·8
"Fissured" bar, as-rolled	27·6	38·0	2·0	3·0

NOTE.—While a comparison between a heat-treated and an as-rolled test is admittedly unfair, the obvious brittleness of the defective bar is clearly brought out.

to find part of a cast showing cracks and part not, when normally cooled. Can it be that some bars have just missed a critical rate of cooling, or have some ingots picked up more hydrogen in the soaking pits or reheating furnaces? Truly, though Professor Andrew and his co-authors have given us the clearest exposition of the subject yet attempted, there are still some aspects of the question to which their conclusions do not appear to supply a completely satisfactory answer.

AUTHORS' REPLY.

In reply the AUTHORS wrote: We are grateful to Mr. Harris for his contribution to the discussion, and we are glad to have the benefit of his practical experience. We fail to see, however, the "contradictions" to which he refers. Whilst it is true that we adopted as standard the practice of soaking in hydrogen for 90 hr. at 1200° C., it is also a fact that we showed that, with $1\frac{3}{4}$-in. dia. specimens, cracks could be produced after only 2 hr. soaking at this temperature. Further, when investigating the effect of soaking time upon the amount of hydrogen retained, it was found that there was no appreciable variation in the hydrogen content when the soaking time was increased from 70 to 140 hr. (Table VII., Part II., p. 216 P), and, therefore, 90 hr. was adopted to give the maximum hydrogen effect.

Mr. Harris has suggested that it is impossible for an open-hearth melt to absorb as much hydrogen as we introduced into our specimens, but recent work has shown [1] that molten steel may actually contain more hydrogen than we ever retained after our treatment. Moreover, by bubbling hydrogen into a 50-lb. crucible melt we have retained in the resulting air-cooled *solid* 3-in. square ingot no less than 10 c.c. of hydrogen per 100 g. of metal. There can be little doubt, therefore, that even greater quantities of hydrogen may be present in industrial steel both in the molten state and, owing to the large sections involved in industrial practice, in the freshly solidified metal.

With the small specimens employed in laboratory experiments relatively rapid cooling is necessary to retain sufficient hydrogen for the formation of cracks. We have found that it is possible for specimens of our standard size to have hydrogen contents of 3·5 c.c. per 100 g. without hair-line cracks, whilst we have obtained cracks in similar specimens containing hydrogen to the extent of 5 c.c. per 100 g. On this basis it would appear that a hydrogen content of some 4 c.c. per 100 g. is necessary for the production of cracks in these small specimens.

As we have replied to other contributors to the discussion, industrial methods of preventing hair-line cracks are generally in keeping with our view that the important factor is the removal of sufficient hydrogen from the metal. Broadly speaking, there are two methods by which hydrogen in solution may be removed from steel. The first consists in heating in an atmosphere in which the hydrogen concentration is low, and this forms the basis of ingot annealing prior to forging. The other method is to cool so slowly that the hydrogen content of the steel is always near that indicated by the solubility-temperature curve of the metal. This process can be carried out even in a hydrogen atmosphere, and accounts for the

[1] Fourth Report of the Oxygen Sub-Committee, *Journal of The Iron and Steel Institute*, 1943, No. II. (advance copy).

experiment described on p. 233 P to which Mr. Harris refers. The shape of the solubility curve indicates that there will be a marked evolution of hydrogen as the steel undergoes transformation, and extremely careful cooling is necessary if this evolution is not to cause trouble. This explains why the depression of the change point is such a crucial factor. The lower the temperature at which the transformation occurs the slower will be the rate of hydrogen diffusion through the steel. If sufficient hydrogen is present and the steel is cooled through the transformation range at a rate that will not permit the solubility-temperature curve to be followed, hydrogen-rich austenite may be retained and this will subsequently give rise to cracks in the manner which we have already described. The critical rate of cooling will be governed by a number of factors apart from the temperature of transformation, and it is probable that the size of the steel section is the most important of these.

Whilst hydrogen in solid solution is removed more or less readily on heating, the difficulty of the complete removal of the hydrogen, particularly from the ingot, is increased by the fact that hydrogen may be stored in blow-holes, &c., in the molecular form or as methane. The production of cracked and sound bars from the same cast to which Mr. Harris refers can probably be correlated with the soundness of the corresponding part of the ingot.

We reported the production of internal cracks in plain carbon steels and in American rail steel, and although the fissures developed in rails are in certain important respects different from hair-line cracks or snowflakes, there seems little doubt from the published work that they owe their origin to hydrogen.

SECTION II.

A SURVEY OF LITERATURE ON THE MANUFACTURE AND PROPERTIES OF IRON AND STEEL, AND KINDRED SUBJECTS.

CONTENTS.

The Editor has been assisted in the preparation of this Survey by
R. A. Ronnebeck.

MINERAL RESOURCES

Iron Deposits of the West of England. F. J. Stephens. (Iron and Coal Trades Review, 1942, vol. 145, Sept. 25, pp. 839–842). The author reviews the history of the iron-ore industry of the south-west of England, which, up to about 1880, was producing large quantities of ore for furnaces in South Wales, and even for the North-East-Coast furnaces. He believes that large quantities are still available in the south-west.

Magnetite-Hematite Relations in the Banded Iron Formations of Western Australia. K. R. Miles. (Proceedings of the Australasian Institute of Mining and Metallurgy, Dec. 31, 1941, No. 124, pp. 193–201). The author gives a brief account of the geology of the banded iron formations of Western Australia, which occur most abundantly in the central and eastern goldfields, where they form portions of the Older Greenstone or Kalgoorlie Series of auriferous rocks.

Ore and Coal in the Ukraine and in the Donetz Basin. (Stahl und Eisen, 1942, vol. 62, Aug. 13, pp. 697–700). A detailed account is given of the coal and ore resources of the Ukraine and Donetz basin, with estimates of the reserves and data on the production in recent years.

The Ferro-Mineral Resources of South America. R. Stappenbeck. (Iron and Coal Trades Review, 1942, vol. 145, Oct. 2, pp. 889–892). An abridged English translation of the author's paper which appeared in Stahl und Eisen, 1942, vol. 62, Apr. 30, pp. 369–373 is presented. (*See* Journ. I. and S.I., 1942, No. II., pp. 87 A).

Manganese Deposits of Costa Rica, Central America. B. N. Webber. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1445: Metals Technology, 1942, vol. 6, Mar.). The author gives an account of the geology of the manganese ore deposits of the Nicoya peninsula of Costa Rica. The ore production reached a peak of 10,000 tons in 1919, but had ceased completely by 1924. The present war has revived interest in this source of supply. Many new deposits have been discovered in the last 20 years, and some new trails have been cut, but actual exploration has not been extensive.

REFRACTORY MATERIALS

Microscopic Examination of Silica Refractories. P. F. F. Clephane. (London and Southern District Junior Gas Association: Refractories Journal, 1942, vol. 18, Sept., pp. 231–241). The author describes the apparatus and technique employed by

the Gas Light & Coke Company to make an accurate estimation of the refractive index of the quartz used as a raw material for making silica bricks. The refractive index of powdered quartz taken from kilned bricks enables a determination to be made of the degree of conversion to cristobalite which has been effected. The procedures for clay-bonded and lime-bonded silicas are different, and both are described.

Mechanism of Wear of Blast Furnace Linings. H. M. Kraner. (Steel, 1942, vol. 111, Aug. 31, pp. 66–75). The author's paper presented at a meeting of the American Ceramic Society is reproduced. (*See* Journ. I. and S.I., 1942, No. II., p. 162 A).

Soaking Pit and Reheating Furnace Refractories. J. H. Chesters. (Iron Age, 1942, vol. 150, July 16, pp. 35–42; July 23, pp. 38–43). After describing several modern types of soaking pits and reheating furnaces, the author discusses the refractories used in them in American and British practice. The most encouraging sphere for improving furnace efficiency lies in design. The recent development of the super-duty brick has reached a more advanced stage in the United States, due to the availability of the Missouri diaspore deposits, from which bricks can be made that will stand up to extremely severe conditions without undue vitrification. In general, soaking-pit and reheating furnace side walls are constructed of medium alumina brick, but low- and high-alumina brick are also employed, and give satisfactory service. The properties of eight bricks that have given good results are included in a table. The outstanding problem as regards the hearth is the method of removing or preventing the adherence of molten scale from the ingots or billets. The present methods represent an unsatisfactory compromise, and it would be better to work with a really fluid slag which could be efficiently tapped off, or to employ some device to enable hard scale to be removed without damage to the hearth below. In recent reheating furnace trials it has been found that stabilised dolomite brick can be protected with a $\frac{1}{2}$-in. layer of "basic" (burned dolomite), which is brushed off the hearth as soon as it becomes slagged with scale.

The Insulation of Furnaces. G. E. Foxwell. (British Steelmaker, 1942, vol. 8, Oct., pp. 266–272). The author explains some calculations respecting thermal conductivity and heat losses due to radiation and convection, and discusses the benefits that can be obtained by insulating industrial furnaces. In general terms, insulation reduces the loss by conduction through the walls without sensibly increasing the mass of brickwork and the corresponding loss by heat storage. Furnaces should therefore be constructed with reasonably thick insulation and with the thinnest practicable firebrick lining, consistent with adequate strength and durability.

FUEL

Julius Robert Mayer and His Mission. W. Ostwald. (Stahl und Eisen, 1942, vol. 62, Aug. 27, pp. 725–726). A brief account is given of the work of J. R. Mayer (born 1814, died 1878), with special reference to that concerned with the conservation of energy and the mechanical equivalent of heat.

A Note on the Relation of Heat Loss and Temperature in Furnaces. G. O. Taylor. (Metallurgia, 1942, vol. 26, Sept., pp. 161–163). For efficient and economical heating in a furnace it is necessary to limit heat losses and, normally, problems associated with these losses involve complex calculations. In this paper the author simplifies the solution of some of these problems by establishing simple laws relating to heat loss, temperature and other factors; these laws will permit of results sufficiently accurate for practical purposes.

Coal Preparation in South Wales. (Iron and Coal Trades Review, 1942, vol. 145, Sept. 25, pp. 851–852). An outline of the methods of preparing coal for market as practised in South Wales is given, the information being based on a publication of the Department of Scientific and Industrial Research entitled "The Coals of South Wales," which forms No. 55 of the series "Physical and Chemical Survey of the National Coal Resources."

Improving the Quality of Upper Silesian Blast-Furnace Coke. W. Stumpe. (Stahl und Eisen, 1942, vol. 62, Aug. 20, pp. 705–713). In the years following the war of 1914–1918 the problem of building much larger blast-furnaces in Upper Silesia was considered, and with this was linked the problem of producing more and better quality coke. In this paper the author reports on full-scale tests at the Julienhütte, in which it was found that the inclusion in the coke-oven charge of up to 20% of low-temperature coke crushed to 2 mm. size greatly improved the properties of the coke, which then had sufficient strength to fulfil blast-furnace requirements.

Production of Benzol Products by the Continuous Process. C. R. Lohrey. (Iron and Steel Engineer, 1942, vol. 19, Aug., pp. 46–51, 54). The author gives a detailed and illustrated account of the plant and processes for the recovery of light oil products at the coke-ovens of the Great Lakes Steel Corporation. The continuous fractionating process is used.

PRODUCTION OF IRON

Economic Aspects of Pre-Compression Refrigerated Dry Blast. R. VD. Dunne. (Iron and Steel Engineer, 1942, vol. 19, July, pp. 56–59). The author presents calculations relative to: (*a*) The

power required for blowing blast-furnace blast under varying conditions of temperature and humidity; (*b*) the cost of operating a dehumidifying plant for a blast-furnace producing 1000 tons per day; (*c*) the capital and interest charges on such a plant; and (*d*) the profit obtained by deducting the gross cost of operating and maintaining the plant from the amount saved in the coke consumption of the blast-furnace.

The Turbo-Blower in Iron and Steel Works. F. Kluge. (Stahl und Eisen, 1942, vol. 62, July 2, pp. 561–567; July 9, pp. 588–591; July 16, pp. 608–609). The author reviews the advantages of using turbo-blowers for supplying blast to blast-furnaces and Bessemer converters, and developments in the design and performance of turbo-blowers in recent years.

Unusually High Production of a Blast-Furnace. H. Schnettler. (Stahl und Eisen, 1942, vol. 62, June 11, pp. 510–511). Statistics relating to the charging and production of No. 4 blast-furnace of the Hoesch A.-G., Dortmund, are presented and discussed. This furnace completed in January 1942 a campaign of almost 14 years, during which it produced 3,380,000 metric tons of pig iron.

Adjustable Voltage Skip Hoist Control. F. R. Burt. (Iron and Steel Engineer, 1942, vol. 19, Aug., pp. 38–40). The author discusses means of controlling the speed of electrically driven blast-furnace charging skips, especially the deceleration on reaching the top. The speed at this point must not vary regardless of whether the skip contains ore or coke. This condition is very difficult to obtain with a motor supplied from a constant-voltage source. An improved adjustable voltage control with a special regulator which meets the above requirements is described in detail.

Desulphurising with Acid Slags when Fluxes Are Added. R. Durrer and B. Marinček. (Stahl und Eisen, 1942, vol. 62, June 25, pp. 537–539). The authors describe some small-scale desulphurisation experiments at 1600–1700° C. using 150 g. each of iron and of acid slags to discover how to reduce the viscosity of the slag and thus permit reaction at lower temperatures. Although higher temperatures favoured the reactions, a high degree of desulphurisation is possible even at ordinary blast-furnace process temperatures with an acid slag and in the presence of carbon, provided that the slag is fluid. The best results were obtained with additions of titania and fluorspar, but it still remains to be discovered whether the titania acts only as a flux, or chemically as well. The quantity of slag is not of much importance in acid desulphurisation. By prolonging the time, the amount of sulphur removed is increased until the iron is almost completely free from sulphur, whilst in basic desulphurisation the process is limited by the point at which the slag becomes saturated with sulphur.

The Thermal Insulation and the Behaviour towards Moisture of Walls of Slag Bricks and Slag Pumice Bricks. J. S. Cammerer. (Stahl und Eisen, 1942, vol. 62, June 11, pp. 503–510). The author

reports the results of a number of laboratory and full-scale tests of the properties of slag bricks for building. These tests established the general conclusion that bricks made in various parts of Germany from blast-furnace slag had better insulating properties than ordinary bricks, despite the high specific gravity and high moisture content of the former. In certain cases the thermal conductivity of the slag bricks is 25% less; this difference decreases with the specific gravity, and is much less with slag pumice bricks. The capacity of the slag bricks to absorb moisture varies greatly for each of the places of manufacture. The usefulness of slag bricks is scarcely affected by the direction the wall faces or by the methods of heating and ventilating the building. Tables and graphs of the moisture-absorption capacity of slag bricks in different periods in relation to the specific gravity are presented.

Powder Metallurgy. (Automobile Engineer, 1942, vol. 32, Oct., pp. 401–402). Some developments and new applications of the powder metallurgy process are described. Oil-pump gears, filters for oil for high-speed Diesel engines and permanent magnets are now made by this process. An advantage of the process which is of great importance in war-time is the virtual elimination of scrap; for instance, a gear profile which is consistently within 0·0001 in. of the true involute can be produced from an accurate die.

The First Cast-Iron Cannon Made in England. H. Schubert. (Journal of The Iron and Steel Institute, 1942, No. II., pp. 131 P–140 P). The iron-casting process was introduced into England at the end of the fifteenth century by French founders, mostly belonging to the King's artillery as gunners in the Tower of London. As a result several ironworks were set up around Ashdown Forest in Sussex before 1500. In one of them, at Newbridge, guns were made with a barrel of cast iron and detachable chambers (mentioned in accounts of 1509–10 preserved in the Public Record Office in London). These are the first cast-iron cannon of English manufacture which can be definitely dated and located. That is thirty-four years before 1543, which, according to historical tradition, is the date of the first casting of iron guns in England known to us. Round about 1509 there was already a considerable home industry in iron in southern England, many of the Frenchmen who introduced the casting process being replaced by English founders. This growing home industry was seriously hampered when Henry VIII. engaged French and Italian metal-founders to cast ordnance of bronze and imported guns from Belgium. A new impetus came in 1543, when Henry VIII. was in need of large quantities of ordnance of cast iron, which was less expensive than bronze. This need led to the revival of the casting of iron guns, first at Buxted, where the French bronze-founder Peter Baude and the English iron-founder Ralph Hogge cast iron guns in the same year. From this attempt dates the great development of the casting of iron ordnance in Sussex,

and later in South Wales also. At that time the quality of English iron guns was improved by casting the barrel and chamber in one whole piece. The improved quality led to an increasing export to the Continent. The English guns of cast iron held a very high position in the European market well into the seventeenth century, when the demand was limited by Swedish and Westphalian competition. For casting heavy iron cannon of large size double furnaces, *i.e.*, a pair of furnaces combined in a single structure, were erected, the first in Worth Forest in Sussex, in 1547. Afterwards the idea of the double furnace was probably introduced from England into France and into the Netherlands, whence it was carried to Sweden and Western Germany.

Hayle Foundry. R. Jenkins. (Newcomen Society: Engineer, 1942, vol. 174, Oct. 16, pp. 327–328). The author gives an account of the history of the Hayle Foundry in Cornwall, which was started shortly before the year 1780 by John Harvey and developed by his nephew. It was an iron foundry making castings for the steam engines and pumps in the Cornish mines. The casting and boring of large cylinders was started soon after 1820. One of the largest cylinders ever cast in one piece was made at this foundry in 1843; it was 12 ft. in dia. and 25 tons of metal were melted for it. A similar engine was made about 1849, and this one remained at work, without interruption, until 1933.

When Charcoal Iron Industry Held Sway. (Steel, 1942, vol. 110, Aug. 3, pp. 80–83, 114–116; Aug. 10, pp. 78–82). An illustrated account is given of the history of the charcoal iron industry of the United States and the part it played in the American War of Independence.

FOUNDRY PRACTICE

Graphitisation of Martensite on Heating. A. Hultgren and O. Edström. (Jernkontorets Annaler, 1942, vol. 126, pp. 83–107). In the production of malleable iron castings the number of graphite particles is very greatly increased and the annealing time correspondingly shortened if the castings are heated and quenched in oil or water before annealing. The following factors contribute to increasing the number of graphite particles: (*a*) A high quenching temperature; (*b*) slow heating through the 400–650° C. range; and (*c*) holding for a short period at 600–650° C. after quenching. This form of treatment is also applicable to alloyed white cast irons except those alloyed with chromium or manganese. No graphite nuclei appear in the cementite, but they appear as finely dispersed particles in the ferrite matrix, and preferentially at the matrix-cementite boundaries. Tensile tests on pre-quenched and malleablised specimens showed a normal tensile strength but

rather poor elongation, only 6–7% for unalloyed iron and still lower for alloyed iron; the cause of this has not been determined. A tentative explanation of the increased graphite nucleation as a result of pre-quenching is given.

Cast Mortar Shells from Electric Furnace Steel. J. B. Nealey. (Iron Age, 1942, vol. 150, Aug. 13, pp. 47–52). The author describes the production of steel and the foundry and heat-treatment technique at an American steel foundry producing 60-mm.-dia. cast steel trench-mortar shells. Four tilting electric acid-lined furnaces with capacities of 2 to 10 tons are used for producing the steel. The shells are cast in a three-part mould consisting of the cope, cheek and drag, with steel and brass patterns for each; sixteen shells are cast in one mould. The heat treatment is carried out in a large gas-fired radiant-tube furnace, the castings being loaded in trays which are pulled through the furnace by chains. A single casting unit of three moulding machines can produce between 9000 and 10,000 shells in 24 hr.

Second Report of the Moulding Materials Sub-Committee of the Steel Castings Research Committee. (Journal of the Iron and Steel Institute, 1942, No. II., pp. 393 P–454 P). Since the publication of the First Report of the Moulding Materials Sub-Committee (*see* The Iron and Steel Institute, 1938, Special Report No. 23, Section V., pp. 87–200) a considerable amount of further research has been carried out and an account of this is given in the present Report. The Report is made up of four sections as follows:

Section I.—Introduction.
Section II.—Moulding Sands.
- Part 1. Examination of Moulding Sands.
- Part 2. The Effect of Milling on the Properties of Moulding Sand.
- Part 3. The Effect of Surface-Tension-Reducing Agents on the Strengths of Moulding Sands.
- Part 4. The Permeability of Moulding Sands.
- Part 5. Thermal Expansion of Sand Mixtures Containing Clays.
- Part 6. The Use of Insulating Heads.
- Part 7. Conclusion and Recommendations.

Section III.—Clays.
- Part 1. The Use of Fuller's Earth in Foundries.
- Part 2. Report on Clays other than Fuller's Earth.

Section IV.—Core Compounds and Core-Sand Mixtures.

An investigation on the production of steel moulding sands has shown that some sandstones containing 7–12% of partially weathered felspathic matter make a useful base for steel-foundry sands; with 10–20% of clay the product has good general properties, and can be diluted with silica sands to provide a range of strength and

permeability. The weathered sandstones of the Wolsingham district of County Durham make a moulding sand satisfactory for steel foundries. The addition of wetting agents to the water used in preparing moulding sands does not appear to increase the rate of spread of the bond clay, and has little effect on the strength of the moulding sand. Investigations of the thermal expansion of sand mixtures containing clay, and of mixtures of low thermal conductivity, suitable for use in certain types of feeder head, have been made. A full description is given of a simple permeability-testing apparatus which gives accurate results for sands of both high and low permeability. In the search for a substitute for bentonite, many tests have been made in collaboration with The Fuller's Earth Union, Ltd., on selected fuller's earths found in Somerset and Surrey, to which the general designation "Fulbond" has been given. In most foundries a marked degree of success has been achieved with recommended fuller's earths; other substitutes for bentonite which have been tested have not proved to be so generally useful as a selected variety of Fulbond. Trials with clay bonds showed that some of them, when used in proportions of 5–10% with a high-silica sand, give satisfactory green strength, but are lower in dry strength than normal Fulbond or bentonite mixtures. The clay-bonded sands have, however, a greater hot strength than the Fulbond or bentonite mixtures. Extensive tests were made to find methods of reducing the consumption of linseed oil and corn-starch products in core binders, and it was found that in many cases up to one-half of the linseed oil in a core mixture could be replaced by Truline binder without detriment to the strength and collapsability of the core. In many instances a reduction in the total quantity of core binders in a core sand can be made without any falling-off in performance. The use of "clay" binders in place of sulphite lye was examined. There are indications that the incorporation of a proportion of naturally bonded sand, a synthetic clay-bonded sand, bentonite, Fulbond, or bond clay gives satisfactory results and renders possible an effective reduction in the proportion of organic binders.

Luminescence Analysis of Core Oils and Core Binders. F. Roll and Annemarie Riess. (Giesserei, 1942, vol. 29, Aug. 7, pp. 269–273). The authors explain the principles employed in the application of luminescence or fluorescence for analytical purposes and then describe in detail how this technique lends itself to foundry use for the control of the quality and properties of core oils and core binders. Tables of results obtained when observing core oils, core binders, core sands and moulding sands under ultra-violet light are presented.

Suspension Conveyors for Foundries. H. Schulze-Manitius. (Giesserei, 1942, vol. 29, Aug. 7, pp. 273–278). The author describes several types of suspension conveyors and their application in foundries. The most recent type is a tubular conveyor in which

the moving chain passes along the inside of a slit tube, and the arms carrying the hook, tray or bucket pass through the slit. The tube needs fewer brackets to support it than an angle-iron chain carrier, it occupies less space and therefore casts less shadow on the working floor space.

PRODUCTION OF STEEL

The Iron and Steel Industry of Australia. (Stahl und Eisen, 1942, vol. 62, June 18, pp. 527–529). An account is given of the history of the iron and steel industry of Australia, with details of the availability of raw materials, the number and capacity of the furnaces and the production of the rolling mills.

August Thyssen. W. Däbritz. (Stahl und Eisen, 1942, vol. 62, Aug. 6, pp. 665–670). The author presents a historical account of the life and work of August Thyssen with special reference to the development of the iron and steel works associated with his name.

Time as a Factor in the Making and Treating of Steel. J. Johnston. (Howe Memorial Lecture: American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1478: Metals Technology, 1942, vol. 9, June). The author discusses some instances in the many processes of making a finished steel product for which in recent years a satisfactory explanation of the influence of time has been put forward. The processes and phenomena dealt with include: (1) The reduction of ore in the blast-furnace; (2) the conversion of iron into steel; (3) the heating of steel products; (4) isothermal transformation; (5) the diffusion of hydrogen in steel; (6) carburisation and decarburisation; (7) stabilisation of structure; and (8) surface phenomena.

The Metallurgy of the Bessemer Process. Theory and Practice. H. Wentrup. (Technische Mitteilungen Krupp, Forschungsberichte: Stahl und Eisen, 1942, vol. 62, Sept. 3, pp. 749–756). The author reviews earlier laboratory investigations of slag-metal reactions, in particular that of Körber and Oelsen (*see* Journ. I. and S.I., 1935, No. II., p. 382 A), and discusses to what extent the conclusions reached are in agreement with observations made on full-scale acid and basic Bessemer plants. In acid Bessemer practice the slags which are formed as reaction products of the oxidation of the carbon, silicon and manganese in the iron correspond in their composition to those which would be formed under equilibrium conditions which are governed largely by the oxygen content of the iron. The changes in the silicon and manganese contents of the metal are therefore in accordance with the conclusions reached in laboratory equilibrium investigations. The oxygen content of

the iron must also be in equilibrium with the ferrous oxide in the slag as governed by the distribution constant. It is only between the carbon in the iron and the ferrous oxide in the slag that there is no equilibrium, for the amount of carbon is always greater than that required for equilibrium. It can therefore be said that the oxidation of the carbon " hangs back " and requires a higher oxygen content in the iron than equilibrium conditions would call for.

After discussing the theory and practice of the basic-Bessemer process the author finds that it is no longer necessary to assume non-equilibrium conditions between the steel and slag in order to explain the behaviour of the lime-phosphate slag.

The Basic Open-Hearth Process To-Day. Part I. The Modern Basic Open-Hearth Furnace. Part II. Melting Practice. W. Geary. (Metallurgia, 1942, vol. 26, Aug., pp. 123–128, 143; Sept., pp. 175–178). After a brief review of the history of the development of open-hearth furnaces for steelmaking, the author discusses in Part I. the influence of bath depth and bath area on the output per hour, the design of gas and air ports including movable water-cooled gas ports, roof design, the tendency to strengthen the structural steelwork of furnaces and methods of constructing checker brickwork. In Part II. the human factor, hearth maintenance and charging are dealt with. It is important to secure adequate drainage of the bottom, and excellent results have been obtained at one plant by burning away after each tap any suggestion of a step in the tap-hole. It is suggested that there is a future for thermal scrap preparation because the air trapped in bundles of sheets and turnings retards the melting by shielding the interior from the flame; the preheating of bundles before charging in the open-hearth furnace would shorten the melting time; such heating could be done with blast-furnace gas or other low-grade fuel.

Iron—Its Use and Effect in Making Basic Open-Hearth Steel. W. C. Buell, jun., J. R. Miller and H. W. Potter. (Steel, 1942, vol. 111, Aug. 17, pp. 78–82, 100–104). The authors describe modifications of the open-hearth process in the United States for the production of steel from charges with over 60% of pig iron. With up to this amount of iron in the charge the basic open-hearth process can be operated successfully along conventional lines. Reasonably good steel can be so produced and, except for the effect of a larger quantity of eliminated metalloids originating from the high pig-iron charge, differs little from steel made from a charge of 50% of pig iron. A process adopted at two American open-hearth plants is that of preparing the iron portion of the charge in a cupola by melting down iron and steel scrap; the metal and slag are tapped off continuously, the iron flowing to a holding ladle and the slag to a cinder ladle. When an iron charge is required the taphole is plugged temporarily and the holding ladle tilted to fill the transfer ladle, which is set on a platform. Soda ash is added while the transfer ladle is being filled. After the action caused by the soda

ash has subsided, the crane picks up the transfer ladle and the metal is poured into the steel furnace.

Recovery and Preparation of Steel Scrap from Steel-Making Furnace Slag and Refuse. F. E. Ullman. (Iron and Steel Engineer, 1942, vol. 19, Aug., pp. 27–32). An abstract of this paper has appeared previously (*see* Journ. I. and S.I., 1942, No. II., p. 169 A).

Galvanized Scrap Burned. (Iron Age, 1942, vol. 150, July 23, p. 57). A short description is given of a method of removing most of the zinc from galvanised steel scrap to make it suitable for charging in steel furnaces. A large pile of the scrap is prepared on suitable open ground with old battery boxes as a base. The battery boxes are ignited, and sufficient heat is generated to burn off most of the zinc.

The Working of the Basic Coreless Induction Furnace. W. Bottenberg and P. Bardenheuer. (Stahl und Eisen, 1942, vol. 62, Aug. 20, pp. 713–718). This is an abridged version of a paper which appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1942, vol. 24, No. 2, pp. 7–22. (*See* Journ. I. and S.I., 1942, No. II., p. 54 A).

A Note on Diffusion in Rimming Steel on Soaking at about 1300° C. T. Swinden and W. W. Stevenson. (Journal of The Iron and Steel Institute, 1942, No. II., pp. 357 P–362 P). In order to ascertain the extent to which diffusion of carbon, if any, takes place at the junction of the rim and core zones of dissimilar carbon contents, the authors subjected a section $1\frac{1}{4}$ in. thick of a $7\frac{1}{4}$-in. square bloom to prolonged heating (46 hr.) at 1300° C. The bloom was of fully rimmed steel with the following pit sample analysis: Carbon 0·09%, manganese 0·34%, silicon trace, sulphur 0·035% and phosphorus 0·017%. There was a slight diffusion of carbon from the core to the rim zone. There was no apparent migration of sulphur from the core to the rim; in fact, the rim-core demarcation was even more sharply defined on the sulphur print after soaking than before. Some observations are made on the changes in constitution and distribution of the inclusions, particularly within the core zone.

Rimming Steel. Additional Studies of the Composition Variation from Outside to Centre. T. Swinden. (Journal of The Iron and Steel Institute, 1942, No. II., pp. 345 P–356 P). This paper represents a continuation of the work reported in Section III. of the Ninth Report on the Heterogeneity of Steel Ingots, with particular reference to the Hultgren and Phragmén hypothesis on rimming action. It deals with a basic open-hearth steel ingot from a cast with a pit-sample carbon content of 0·047% and containing only 0·10% of manganese. No essential difference in the type of inclusions was found as compared with rimming steel of more normal composition. Variations in composition as regards carbon and oxygen (and also hydrogen and nitrogen) have been traced. The data

thus obtained provide excellent verification of the hypothesis postulated by Hultgren and Phragmén, and the actual values of carbon and oxygen representing the balanced composition, namely, 0·06% carbon and 0·04% oxygen, appear to be substantially correct.

Rimming Steel. Report on Four Ingots of Basic Bessemer Steel. J. Mitchell. (Journal of The Iron and Steel Institute, 1942, No. II., pp. 327 P–344 P). A study has been made of four low-carbon basic Bessemer steel ingots of British manufacture—all cast from the same blow. As far as possible the conditions of manufacture and examination were kept constant, in order that the effect of mould size might be studied. The data given include steelmaking practice, sulphur- and macro-prints of ingot sections and analyses of these sections at selected positions. These are reviewed in their relation to rimming-steel practice and theory.

The Formation of Hair-Line Cracks. Part II. J. H. Andrew, A. K. Bose, H. Lee and A. G. Quarrell. (Journal of The Iron and Steel Institute, 1942, No. II., pp. 203 P–243 P). The work described in Part I. (*see* Journ. I. and S.I., 1942, No. II., p. 171 A) is confirmed and greatly extended.

Typical hair-line cracks were produced in large specimens which had been air-cooled after hydrogen-soaking, but the bulk of the work was carried out on small specimens which had been hydrogen-treated and quenched. The evolution of gas from such specimens, both at room temperature and on heating, was investigated, and the nature of the incubation period is explained.

The results obtained lead to the following conclusions: (i) Hydrogen is the fundamental cause of hair-line cracks. (ii) The hydrogen which subsequently causes cracks is not in solid solution, but, for a time, is held in the form of a hydrogen-rich constituent which is formed on rapid cooling through the γ–α change. (iii) Breakdown of the constituent releases hydrogen, some of which diffuses into voids and builds up a disruptive pressure. (iv) In addition to hydrogen, the cracks contain methane, even at room temperature, and the presence of this methane is the cause of some of the difficulties encountered in the industrial prevention of hair-line cracks. (v) The influence of composition upon the susceptibility of a given steel to hair-crack formation is explained by the effect of composition upon the stability of the resulting hydrogen-rich constituent. (vi) Finally, once the constituent has been formed, its breakdown at low temperature must lead to hair-crack formation; on the other hand, hair-line cracks will not result if the breakdown of the constituent can be brought about at a sufficiently high temperature.

General Rules for Costing in Industry. A. Müller. (Stahl und Eisen, 1942, vol. 62, Aug. 13, pp. 695–697).

FORGING, STAMPING AND DRAWING

Manufacture of Heavy Forgings in Alloy Steel. A. V. Jobling. (Journal of the Junior Institution of Engineers, 1942, vol. 52, Sept., pp. 285–295). The author discusses, for the benefit of the design engineer, some of the problems which face the steel manufacturer in the production of heavy forgings in alloy steels. He deals first with information required by the designer, such as the final dimensions and the extent to which the standard mechanical tests provide information on the suitability of a forging for a particular purpose. Secondly, he describes the structure of a large ingot, forging methods and their effect on the structure, mass effect and the influence of alloying elements. Finally, the necessity for heat treatment and the prevention of hair-line cracks are considered.

Truing Device for Wire-Drawing Dies. J. Baker. (Machinery, 1942, vol. 61, Sept. 24, pp. 340–341). A device is described and illustrated which is very useful when it is required to machine small circular bodies with central holes truly concentric, although the holes are tapered and the axis of the hole may not be perpendicular to the face of the part. It enables the cylindrical and end faces of the body to be machined true to the hole at one setting. The particular application described is that of manufacturing tungsten-carbide wire-drawing dies.

ROLLING-MILL PRACTICE

Special Sheet Rolling Mill at Commonwealth Steel Company's Works. A. G. Cunningham. (B.H.P. Review, 1942, vol. 19, June, pp. 12–13). A brief description is given of the sheet department at the Waratah Works (N.S.W.) of the Commonwealth Steel Co. The mill comprises two two-high stands with chilled iron rolls 60 in. long $\times$ 32 in. dia. It was originally installed to roll stainless and heat-resisting steels, but steels for hack-saws, files, surgical instruments and high-speed tools are now also rolled. Some particulars of the reheating furnaces, heat-treatment furnace and pickling plant are also given.

Adapting Wide Strip Mills to European Conditions. H. P. Lemm. (Iron and Coal Trades Review, 1942, vol. 145, Sept. 25, pp. 853–856). An abridged English translation is presented of the author's paper which appeared in Stahl und Eisen, 1942, vol. 62, Mar. 26, pp. 257–265. (*See* Journ. I. and S.I., 1942, No. II., p. 59 A).

New Cold Rolling Mill at Newcastle Steel Works. J. T. Todhunter. (B.H.P. Review, 1942, vol. 19, June, pp. 1–4). The

author gives a brief illustrated description of a new cold-strip mill at the Newcastle (N.S.W.) Works of the Broken Hill Proprietary Co., Ltd., where strip from $\frac{3}{8}$ in. to 12 in. wide can be rolled in any gauge from 0·187 in. down to 0·010 in.

Armco Introduces Sendzimir Mill. (Iron Age, 1942, vol. 150, July 23, pp. 55–57). A description is given of the first Sendzimir rolling-mill to be put in operation in the United States. This unusual type of cold-strip mill is small in size and very efficient. The mill makes use of cluster backing rolls, so that the work rolls are quite small—*i.e.*, between 1 in. and 4 in. in dia. Stainless and high-carbon steel strip can be rolled, and the reducing power is so great that fine gauges can be rolled from hot-rolled strip without any intermediate annealing.

Output and Production Costs. A. E. Lendl. (Iron and Steel, 1942, vol. 15, Sept., pp. 438–442). The author studies methods of calculating the influence of the output per hour of a rolling-mill on the conversion costs of a section. The various items of the conversion costs are criticised, and actual figures are given for an existing strip-mill. Convenient diagrams are developed which should be a valuable instrument for the quick checking of the conversion costs.

The Highest Attainable Reductions when Cold-Drawing Seamless Tubes of Soft Steel in a Piercing Mill. H. Frank. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1942, vol. 24, No. 9, pp. 1–18; Stahl und Eisen, 1942, vol. 62, Sept. 3, pp. 756–760). The author discusses factors affecting the degree of reduction which can be obtained in tube-piercing mills, in particular the effects of the quality of the steel and the drawing conditions. The maximum attainable degree of reduction in the cold-drawing of tubes in a piercing mill is related to the product of the maximum strength-increment factor (*Verfestigungswert*, the ratio of the strength of the product to the mean of the strengths before and after drawing), the deformation efficiency (*Formänderungswirkungsgrad*, the ratio of the ideal to the actual work of deformation) and the strengthening efficiency (*Anstrengungsgrad*, the ratio of the mean drawing force to the tensile strength of the product). Tests with soft steels showed that a maximum reduction of 56·6% could be attained. The greatest strength-increment factor was obtained with a rimming open-hearth steel, annealed before drawing. The maximum attainable deformation efficiency is greater for rimming than for killed steels. The conditions of drawing have a greater influence on the results obtained than that of the preliminary heat treatment. The greatest strengthening efficiency was obtained with a killed steel.

Association of Iron and Steel Engineers Specifications for Electric Overhead Travelling Cranes for Steel Mill Service. (Iron and Steel Engineer, 1942, vol. 19, Aug., pp. 2-CS–28-CS). This constitutes the fourth revision of the specifications for heavy-duty overhead

travelling cranes for rolling-mills which were first drawn up in 1910 by the Association of Iron and Steel Engineers.

HEAT TREATMENT

Heat Treatment. D. C. Harries. (Journal of the Institution of Production Engineers, 1942, vol. 21, Sept., pp. 345–357). The author explains the fundamentals of the heat treatment of carbon steels and the purpose of adding alloying elements, and describes the precautions to be taken to prevent cracking and distortion in heat-treatment operations.

Heat Treatment of Steel Forgings. A. F. Macconochie. (Steel, 1942, vol. 111, Aug. 17, pp. 75–76, 110–113). The author explains the theory of the heat treatment of steel and briefly describes some modern equipment for heat-treating forgings. He refers to two readily distinguishable mechanisms by which austenite transforms. The first, characteristic of annealing and normalising operations, involves the simultaneous formation of ferrite and carbide layers directly from austenite by a steady encroachment of approximately parallel plates or lamellæ upon the receding austenite boundary. The second, generally known as the acicular reaction, and characteristic of hardened steel, is marked by the successive abrupt formation of flat plates of supersaturated ferrite along certain crystallographic planes of the austenitic grains.

The Suitability of Propane and Mixtures of Propane and Acetylene for Flame-Hardening. V. Thürnau. (Autogene Metallbearbeitung, 1940, vol. 33, Apr. 15, pp. 93–98; May 1, pp. 105–115). The author reports on a complete investigation of the commercial and technical possibilities of using propane or propane-acetylene mixtures for flame-hardening steel. The use of propane was found to be unsuitable on economic grounds, not so much because of its low rate of combustion or low flame temperature, but rather because of the chemical composition of propane, which requires so much oxygen to burn it in a manner suitable for flame-hardening that the cost is prohibitive.

Development and Present Position of Flame-Hardening on the German State Railways. C. Stieler. (Autogene Metallbearbeitung, 1940, vol. 33, Oct. 1, pp. 229–237). The author describes and illustrates numerous examples of parts used by the German State Railways, which are subject to heavy wear and have been successfully flame-hardened in the State Railway workshops.

Flame-Hardening with Excess of Oxygen. E. Zorn. (Autogene Metallbearbeitung, 1941, vol. 34, Jan. 1, pp. 13–15). The author reports on an investigation of the results obtained when flame-hardening with the oxy-acetylene torch using a high proportion of oxygen. As the material is heated to only 800–850° C. the oxygen

comes in contact with solid, not molten, iron and, as the quench follows closely after the flame, there is little chance of the iron being oxidised. It was found that by adjusting the oxygen/acetylene ratio to about 1·75/1 the metal was efficiently heated with a saving of about 50% in the consumption of acetylene, *i.e.*, the excess of oxygen was obtained by cutting down the acetylene. Data on the velocity of gases leaving the burner, the hardness and depth of hardness obtained and the consumption of gases are presented.

Flame-Hardening of Round Surfaces. S. Smith. (Welding Journal, 1942, vol. 21, July, pp. 443–448). This paper has also appeared in Steel, 1942, vol. 111, July 20, pp. 76, 82, 97, 98 and Aug. 3, pp. 92–95, 119. (*See* Journ. I. and S.I., 1942, No. II., p. 213 A).

Cast Iron Borings for Steel Surface Protection. D. L. Ellis and J. F. Oesterle. (Iron Age, 1942, vol. 150, July 30, pp. 45–49). The authors describe some experiments undertaken to determine to what extent cast-iron borings as packing material for steel undergoing heat treatment protect the steel from scaling and decarburisation. Specimens of Armco iron and of four steels containing respectively 0·17%, 0·40%, 0·65% and 1·04% of carbon were packed in clean, dry grey-iron borings and heated for 6 hr. at 1550° F., and the effect of mixing a little soda ash with the borings was also tested. There was a slight decarburisation of the 1·04% carbon steel, but the 0·65% and 0·40% carbon steels were unaltered; when soda ash was added, however, these two steels were carburised to about 0·80% of carbon, whilst the 1·04% carbon steel was unchanged. The addition of soda ash energises the reaction and causes carburisation of the lower carbon steels.

Furnace Atmospheres. (Automobile Engineer, 1942, vol. 32, Oct., pp. 415–418). A review of recent developments in the United States of heat-treatment furnace atmospheres is presented. The compositions and applications of six atmospheres developed by the General Electric Co. are given. The Hypercarb process is described (*see* Journ. I. and S.I., 1941, No. I., p. 162 A) with particular reference to factors affecting the design of suitable equipment to operate it.

Weight Change as a Criterion of Extent of Decarburization or Carburization. R. W. Gurry. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1470: Metals Technology, 1942, vol. 9, June). Experimental observations of the loss in weight of a steel specimen after various time intervals during decarburisation at constant temperature, when interpreted on the basis of an integrated form of the fundamental diffusion law, show that, at any one temperature, the absolute weight loss can be predicted within 3·5% by using a properly selected mean value of the diffusion coefficient of carbon in iron, in spite of the fact that this coefficient varies appreciably with the carbon concentration.

The mean coefficient thus derived, values for which are given for a series of temperatures in the 1400–2100° F. range, agrees very closely with that interpolated from the measurements of Wells and Mehl for a carbon content corresponding to half-saturation. Using this mean coefficient in conjunction with other data presented, the amount and distribution of carbon that would be present after any time interval can be calculated for a steel cylinder or plate maintained at a uniform temperature in a carburising or decarburising atmosphere, provided that certain easily attainable conditions are maintained, and that all the carbon in the steel remains in solution.

The Vagaries of 4S11. B. Thomas. (Metallurgia, 1942, vol. 26, Aug., p. 144). The author reports and discusses some results obtained in the heat treatment of British Standard aircraft steel 4S11. This is a low-alloy steel containing nickel, chromium and molybdenum. In the case of a small forging, the accepted temperatures of treatment had to be modified.

WELDING AND CUTTING

Arc Welding and War Production. E. C. Davies. (Engineer, 1942, vol. 174, Sept. 25, pp. 255–257; Oct. 2, pp. 275–276). The author emphasises the necessity of examining existing methods of manufacture with the object of introducing fabrication by arc welding as a means of replacing riveting, iron and steel casting and forging in order to speed up production and to conserve material and labour. It is suggested that by modernising welding methods and taking advantage of the latest information on high-speed welding technique, the time at present required for welding operations could in many instances be materially reduced. Some notes are appended on the relative merits of D.C. and A.C. welding and on the application of single and multi-operator types of equipment.

Gas Welding of Cast Iron. (Iron Age, 1942, vol. 150, Aug. 6, pp. 58–62). Details are given of methods of instructing beginners in the technique of welding cast iron, together with information on how to construct a simple charcoal furnace for preheating an iron casting preparatory to repairing it by welding.

Investigation of the Thermal Conductivity of Weld Metal. Baumgarte and Klosse. (Autogene Metallbearbeitung, 1940, vol. 33, June 15, pp. 152–153). The authors describe a series of tests on welded and unwelded specimens of steel undertaken to ascertain whether the weld increased or decreased the thermal conductivity. The welded specimens had practically the same thermal conductivity as the plain ones, whilst welding improved the electrical conductivity slightly.

The Importance of the Welding Gas and Its Composition in Relation to the Fissure-Formation Tendency of Aircraft Steels. J. Müller. (Autogene Metallbearbeitung, 1940, vol. 33, Nov. 15, pp. 277–281). The author reports the results of investigations of the effects of impurities in welding gases on the tendency to crack formation of welded chromium-molybdenum steels used in aircraft manufacture. The conclusions reached were: (1) It makes absolutely no difference to the fissure-formation tendency of either unalloyed or alloyed aircraft steels whether the acetylene used for welding is drawn from cylinders or direct from generators. (2) The amount of sulphur- and phosphorus-bearing impurities normally present in welding gases is so small as to have no measurable effect on the fissure-formation tendency; all the same, it is advisable to use gases which are as pure as possible. (3) The presence of between 0·03% and 0·8% of hydrogen sulphide has no effect, but 0·9% and upwards has a very detrimental effect. (4) The presence of 0·1–0·12% of phosphine in the welding gases does not affect the fissure-formation tendency. (5) If both hydrogen sulphide and phosphine are present to the extent of 0·8% or more they have a very detrimental effect.

The Causes of the Fissure-Formation Tendency in Welded Chromium-Molybdenum Structural Steels. A. Antonioli. (Stahl und Eisen, 1942, vol. 62, June 25, pp. 540–545). Notched-bar impact tests at high temperatures have revealed that steels with a tendency to fissure-formation on welding are brittle at temperatures above 1300–1350° C.; this is characterised by the formation of intercrystalline cracks. In this paper the author describes experiments carried out at the Istituto Scientifico-Tecnico Ernesto Breda with electrical apparatus developed by himself. The object was to determine, by tests on weld beads 10 mm. long, the temperature at which cracks formed. From the results of many tests it was found that cracks formed most frequently in the 1350–1000° C. range, the point of maximum frequency being 1275° C., which was a little below that established by impact tests. With longer beads the cracks formed at lower temperatures. This shows that, after welding, the material passes through a temperature range in which embrittlement takes place, and this, of course, is detrimental because micro-cracks form in this range which, on further cooling, increase in size owing to the occurrence of internal stresses. The oxygen content is the principal factor governing the fissure-formation tendency. The tests described were made with steels containing about 0·3% of carbon, 1% of chromium and 0·25% of molybdenum, and the author worked out the factor

$$200 \times \%O_2 + 60 \times \%S - 3 \times \%Mn,$$

the value of which varies directly with the fissure-formation tendency of these steels.

Hard Facings of Stainless Steel Applied by Arc Welding. A. N. Shashkov. (Autogennoe Delo: Welding, 1942, vol. 10, Oct., pp. 200–201). The author reports the results of hardness tests on stainless-steel facings applied to low-alloy steel by arc welding. Two types of base metal were used containing chromium 0·10% and 0·60%, and nickel 0·40% and 1·56% respectively, the latter with 0·27% of molybdenum, and the electrodes contained 14·8% of chromium and 0·39% of nickel. The experiments showed that the electrodes used were very suitable for hard-surfacing both these steels. Narrow beads could be deposited without any special preparation, but for facing large surfaces, preheating the part to 300–400° C. was necessary to eliminate the danger of cracking. Hard-surfacing with these electrodes is recommended for facing hot-stamping tools.

Hard Alloys for Deposition by Welding. P. Wimmer. (Autogene Metallbearbeitung, 1941, vol. 34, Mar. 15, pp. 105–109). The author reviews the properties of special alloys which are used for the hard-surfacing of steel including the high-manganese low-chromium steels and alloys containing various amounts of tungsten and cobalt. The welding technique for depositing them is also described.

Weld Hardening and Steel Composition. A. Edson. (Welding, 1942, vol. 10, Oct., pp. 202–205). The author develops an equation which relates the maximum hardness of the heat-affected zone in a plate which has been electrically welded to the composition of the plate (*see* Metals and Alloys, 1942, vol. 15, June, pp. 966–971 and Journ. I. and S.I., 1942, No. II., p. 175 A).

Determination of the Excess of Acetylene in Relation to the Blue-Flame Length and Carburisation Tests in Deposition Welding. V. Trunschitz. (Autogene Metallbearbeitung, 1942, vol. 35, Jan. 1, pp. 2–12). From the results of tests with the oxy-acetylene welding torch and on metal deposited with it the author established a method of calculating the amount of excess acetylene from the ratio of the blue-flame length to that of the small white cone in the flame. He also plotted curves showing the relation of the increased hardness obtained to the amount of excess acetylene. The limit of weldability using a flame with excess acetylene is reached when the above ratio is 2·5–3·0.

A Comparison of the Most Important Points in the German, English, Swedish, Swiss and American Specifications for the Welding of Land Boilers. K. Vigener and M. Vandelt. (Autogene Metallbearbeitung, 1940, vol. 33, Nov. 1, pp. 261–269; Nov. 15, pp. 282–288).

Advances in Electric Welding of Tubes. D. A. Johnston. (Iron Age, 1942, vol. 150, July 23, pp. 44–45). The author describes some improvements in machines for electric welding tube strip into tubes. The most efficient method of bringing the current to the welding electrodes is by rotating the transformer and electrode

rolls on a common shaft, the current being carried to the primary side of the transformer by means of a commutator and brush. On the secondary side the current is carried through a copper sleeve on which is mounted one of the electrode rolls. The return current passes through another electrode roll mounted on another copper sleeve insulated from the first. The entire transformer and electrode roll assembly rotates on anti-friction bearings.

Manufacture of Electric Resistance Welded Pipe and Tubing. J. S. Adelson. (Iron and Steel Engineer, 1942, vol. 19, Aug., pp. 33–36). The author describes and illustrates the Johnston process of making steel tubes as practised by the Republic Steel Corporation. The mill machinery can produce tubes from ½ in. in dia. × 0·025 in. wall up to 16 in. in dia. × 0·5 in. wall. The cold flat pickled steel strip passes through a series of forming rolls in the welding machine which brings it to a circular section of the required size. The welding unit welds the longitudinal seam by the electric resistance process by means of a pair of disc electrodes mounted on one shaft but insulated from each other. These electrodes make contact on opposite sides of the butted seams. Three supporting rolls with contours to fit the diameter of the finished tube exert mechanical pressure on the tube during the welding process, and a trimming device removes any surplus metal from the inside and outside surfaces. The tube then passes through sizing rolls, is normalised or annealed, and finally is treated to give it a blue oxide coating.

A New Hammered Resistance Welding Process. A. L. Pfeil. (Iron and Steel Engineer, 1942, vol. 19, Aug., pp. 42–45). The author describes a process for the welding of tubes which is a combination of electric resistance welding and hammering. The current for the resistance welding is supplied by disc electrodes as described in the preceding abstract, but the machine is different, in that there is a pneumatic or electrically operated hammer between the electrodes and above the edges to be joined; this makes rapid blows on the weld as it is heated and fused together, an action which can be continued during the cooling cycle if desired.

Welding in Cold-Strip Processing. J. H. Cooper. (Iron and Steel Engineer, 1942, vol. 19, July, pp. 46–53). The author describes and illustrates the development of two types of electric welding machine used in cold-strip mills. These types are for making spot welds to join the overlapping ends of two lengths of strip, and for flash-butt welding coil ends respectively.

Performance of Various Gases in the Oxygen Cutting Process. P. L. Betz. (Iron and Steel Engineer, 1942, vol. 19, July, pp. 64–71). The author describes an investigation of the relative merits of three fuel gases in combination with oxygen for cutting steel plates. The fuel gases were acetylene, Baltimore city gas and a mixture of blast-furnace and coke-oven gas with a calorific value of 500 B.Th.U. The conclusions reached were: (1) The proper

ratio of preheating oxygen to fuel in the case of city gas and blast-furnace/coke-oven gas is about 0·9, whereas with acetylene it is approximately 2·0; (2) justification was found for using an oxygen/fuel ratio of 2·0 for acetylene instead of the theoretical ratio of 2·5; (3) cutting tests on $1\frac{1}{4}$-in. and $1\frac{1}{2}$-in. steel plates indicated that when city gas or coke-oven/blast-furnace gas was used as a fuel, cutting results similar to those with acetylene were obtained, provided that the same oxygen pressure and volume of cutting-oxygen were used in each case; (4) the volume of preheating fuel gas should be adjusted so as to provide the same heat input as with acetylene; (5) the starting time with the last two fuel gases is somewhat longer than when using acetylene; (6) the starting time can be reduced by nicking the edge of the work where the cut is to be commenced. A procedure is outlined by which the required characteristics of a gas-cutting nozzle may be determined from the characteristics of acetylene cutting nozzles known to be suitable for the work under consideration. Data on the cutting rates, gas consumptions and pressures in the various tests are presented.

CLEANING AND PICKLING OF METALS

Dry-Cleaning Fluids Speed Arms Production. (Iron Age, 1942, vol. 149, June 18, pp. 64–65, 124). A brief review of the development and applications of solvents for degreasing, especially in arms production, is presented.

Cleaning Pipe by Shot Blasting. (Iron Age, 1942, vol. 150, July 30, p. 62E). A brief description is given of two "Wheelabrator" shot-blast units for cleaning the inside and outside surfaces of steel tubes from 2 to 14 in. in dia. in lengths of 18–50 ft. As an example of the rate of cleaning which can be attained, a $4\frac{1}{2}$-in.-dia. tube can be cleaned at 18 ft. per min. on the outside and 14 ft. per min. on the inside.

Mechanical Handling Devices Speed Cleaning of Shell and Bombs. (Steel, 1942, vol. 110, June 1, pp. 88–90). An illustrated description is given of a shot-blasting unit for cleaning the inside and outside of shells and bombs and of the overhead conveyor system which feeds it.

The Autogenous Deseaming of Steel Ingots with the Acetylene Burner. G. Calbiani. (Autogene Metallbearbeitung, 1940, vol. 33, Sept. 15, pp. 217–226). The author describes an investigation of the effects of autogenous deseaming on the properties of steel ingots. Eleven qualities of steel were tested. These included: (*a*) Low, medium and high carbon steels; (*b*) manganese-molybdenum steel; (*c*) chromium-molybdenum steel; (*d*) manganese-silicon-vanadium steel; (*e*) chromium-nickel case-hardening steel;

and (*f*) heat-resisting chromium-silicon steel. Numerous macrographs and micrographs are reproduced and the results of hardness and bend tests are given. It was found that the deseaming had a quite unimportant and temporary local effect on the surface and this effect completely disappeared in the subsequent reheating and working-up processes. A comparison of the costs of deseaming with oxygen and of cleaning with the pneumatic chisel is made and this shows that the former costs very much less than the latter.

Flame Descaling Minimizes Surfacing Time and Costs. E. W. Deck. (Steel, 1942, vol. 110, June 1, pp. 81–84; June 8, pp. 86–88, 115). The author describes and illustrates the process of descaling blooms, plates and bars with the oxy-acetylene flame; specially shaped burner heads with adjustable guides to suit bars of different diameters are available. The process offers considerable saving of time as compared with grinding, and in some cases it is used for plates instead of a weak pickling to prepare them for inspection.

Practical Suggestions for Increasing Pickle Room Output. W. G. See and W. H. Graham. (Wire and Wire Products, 1942, vol. 17, Mar., pp. 146–149). The authors point out that as well as installing further pickling tanks, there are other ways of increasing the output of a pickling plant. Attention should be given to the time taken by the crane to complete a cycle of operations, because the plant output is often limited by this. Preliminary drying of wire by a current of air as the wire leaves the lime vat and the possibility of decreasing the baking time are other methods of increasing output. The use of submerged combustion burners for heating the tanks in a manner which agitates the solution is also advocated.

Submerged Combustion Heating for Pickling Baths. W. G. See. (Iron and Steel Engineer, 1942, vol. 19, June, pp. 62–65). The author describes a completely automatic submerged burner for heating pickling baths. The control equipment for this burner is now so well developed that it can be set to maintain the bath temperature within a very narrow range. Acid-resisting equipment is now available with a guaranteed life of one year and an expected service life of two years. The high thermal efficiency coupled with the saving in acid and over-all pickling time make the installation an economic one.

Cathodic Pickling in the Presence of Inhibitors. W. Machu and O. Ungersböck. (Iron and Steel Institute, 1942, Translation Series, No. 102). This is an English translation of a paper which appeared in Archiv für das Eisenhüttenwesen, 1942, vol. 15, Jan., pp. 301–306. (*See* Journ. I. and S.I., 1942, No. II., p. 23 A).

COATING OF METALS

A New Metal Coating Process. A. E. Bellis. (Wire and Wire Products, 1942, vol. 17, May, pp. 244–246, 253–255). The author describes a process of hot-dip coating for wire or strip with metals such as zinc, babbitt metal, cadmium and tin. The feature of this process is that the wire (or strip) is cleaned, fluxed and preheated by passing it through a bath of molten salt before it enters the metal bath. Particulars of the salt bath are not given.

The Origin of the Impurities in Metallic Coatings and Their Effect on the Corrosion. A. Glazunov. (Korrosion und Metallschutz, 1941, vol. 17, Nov., pp. 387–390). The author points out that electro-deposited metallic coatings are never completely free from impurities. He divides the impurities into two main groups, *viz.*, intercrystalline ones, which form phases of their own, and intracrystalline ones, which are taken up in the lattice of the metal coating. These two groups are sub-divided into numerous further groups, and the origin of the impurities of each group and their effect on the physical and chemical properties of the coatings are discussed. It is possible to modify the quantities of the impurities as well as their properties by altering the conditions of the electrodeposition.

The Spectroscopic Determination of the Thickness of Electro-deposited Coatings. M. Passer and A. Lauenstein. (Korrosion und Metallschutz, 1941, vol. 17, Nov., pp. 380–384). The authors described some time ago two methods for the determination of the thickness of electro-deposited coatings by means of spark spectra (Metallwirtschaft, 1940, vol. 19, pp. 667–672; 1941, vol. 20, pp. 209–215), which are briefly outlined in the present paper. In the first method the intensities of certain lines of the spark spectrum are compared with those obtained under identical conditions from standard specimens, whilst in the second method the time elapsing until a certain intensity of the spectrum of the base metal is reached is taken as a measure of the thickness of the coating. In the present paper the authors describe the application of these methods to the determination of the thickness of chromium coatings on iron and brass sheets, bars and tubes. In conclusion they report on attempts to apply their methods also to the study of tin coatings, which, however, owing to the low melting point of tin, proved unsuccessful.

Electro-Magnetic Apparatus for Fault-Finding and for Determining the Thickness of Non-Magnetic Coatings. S. D. Entin. (Journal for Material Testing, U.S.S.R.: Sheet Metal Industries, 1942, vol. 16, Sept., pp. 1326–1328). Descriptions are given of some testing instruments developed at the Tzniitmach Magnetic Laboratory (U.S.S.R.). The first is a magnetic instrument for detecting cracks in metals. The second is an electromagnetic apparatus for determining the thickness of non-magnetic coatings

and for checking the uniformity of the surface structure of a non-magnetic coating. The third is a magneto-metallographic analyser developed by Eremin for obtaining pictures of the microstructure of heterogeneous magnetic alloys; for this purpose magnetised polished sections are covered with stable magnetic colloids with a particle size of about 10^{-5} cm. and examined at a magnification of 500 diameters.

The Deposition of Chromium from Chromic Acid Solutions on an Industrial Scale. R. Bilfinger. (Korrosion und Metallschutz, 1941, vol. 17, Aug., pp. 282–287). After a general review of the properties of electro-deposited chromium coatings, the author discusses the possibilities of their application for surface protection as well as for decorative purposes and reviews the plating techniques suitable for various cases, discussing in particular the factors affecting the hardness of the deposits.

The Effect of the Temperature on the Deposition of Chromium from Chromic Acid Solutions. N. D. Birükoff and S. P. Makariewa. (Korrosion und Metallschutz, 1941, vol. 17, Aug., pp. 287–291). The authors studied the effect of the temperature on the value of *K*, *i.e.*, a factor which is expressed by

$$\frac{\% \mathrm{Cr}_{(3)}}{\% \mathrm{Cr}_{(m)}} \times 100$$

and represents the ratio of the rates of the electro-chemical reduction of CrO_3 to Cr by atomic hydrogen to that of the purely chemical re-oxidation by dissolution of the cathode. The results are represented graphically and in tables.

The Effect of an Addition of Sulphuric Acid to the Chromic Acid on the Oxidation-Reduction Phenomena Involved in Chromium-Plating. N. D. Birükoff and G. I. Melichow. (Korrosion und Metallschutz, 1941, vol. 17, Aug., pp. 294–297). The authors studied the effect of the concentration of sulphuric acid on the *K* value (*see* preceding abstract) and on the grain size of the deposited chromium.

The Effect of Trivalent Chromium on the Kinetics of the Electro-Deposition of Chromium. N. D. Birükoff, S. P. Makariewa and N. D. Podobed. (Korrosion und Metallschutz, 1941, vol. 17, Aug., pp. 291–294). The authors studied the effect on the electro-deposition of chromium of the presence of $Cr(OH)_3$ formed by the reduction of chromic acid as well as by that added as such to the electrolyte.

Soviet-Russian Results in the Field of Hard-Chromium Plating. M. von Pohl. (Korrosion und Metallschutz, 1941, vol. 17, Aug., pp. 297–299). This review is based on information given by D. V. Pletnev in 1937 in a Russian corrosion journal and in 1940 in a pamphlet on chromium plating in the manufacture of wear-resistant machine parts.

Recent Developments in the Field of Hard-Chromium Plating. J. Fischer. (Korrosion und Metallschutz, 1941, vol. 17, Aug.,

pp. 265–276). The author reports on his study of the electrodeposition of chromium from a chromic-acid bath containing a mixture of hydrofluoric and fluosilicic acids in a certain proportion, which is not stated in the paper. This bath is more stable than baths containing only one of these two acids. Its advantages, as compared with the generally used bath acidified with sulphuric acid, are higher current efficiency, and greater brilliance and hardness of the deposits. Further, it allows of the production of thicker deposits and of renewed treatment of previously coated articles. In conclusion the anti-corrosive value of chromium coatings is discussed briefly, and results of salt-spray tests are reported; these indicate that coatings produced by the new method are more resistant than those deposited from solutions acidified with sulphuric acid.

The Electrodeposition of Hard Nickel. W. A. Wesley and E. J. Roehl. (Electrochemical Society, Oct. 1942, Preprint No. 82–1). The authors present a brief report of the results of recent laboratory and pilot-plant investigations of plating baths for obtaining hard nickel deposits. Nickel coatings with a hardness of 380–480 Vickers can be produced of sufficient thickness and good quality for industrial and engineering applications. Important improvements in the quality of the product can be accomplished by replacing the old type of hard-plating bath with one containing nickel sulphate $NiSO_4.7H_2O$ (180 g. per litre), ammonium chloride NH_4Cl (25 g. per litre), and boric acid H_3BO_3 (30 g. per litre). This electrolyte is well buffered, contains sufficient chloride to ensure high anode efficiency and is therefore easy to maintain at a constant *p*H value. Heavy deposits can be made which are free from laminations, sound in structure, with a high hardness and a high tensile strength coupled with measurable ductility.

Nickel-Plating with Low *p*H Values. R. Springer. (Korrosion und Metallschutz, 1941, vol. 17, Dec., pp. 397–401). The author reviews work (mainly American and English) published during the last decade on the electrodeposition of nickel from acid solutions with *p*H values between 1·0 and 2·5, and emphasises the advantages due to such low *p*H values.

Electrolytic Lead Coatings Deposited from Solutions of Complex Lead-Salts. A. Glazunov and L. Jenicek. (Korrosion und Metallschutz, 1941, vol. 17, Nov., pp. 384–387). The authors developed a method for the electrodeposition of lead by which thin, brilliant and non-porous coatings can be produced, the adherence of which on iron is so satisfactory that no intermediate layers are required. It is stated that an electrolyte with a complex lead cation is used, but no details of the method, for which a German patent has been applied, are given.

Electro-Galvanising Sheet and Strip from the Point of View of Mass Production. G. G. J. Adey. (Sheet Metal Industries, 1942, vol. 16, Sept., pp. 1309–1314). The author describes the plant and sequence of operations for the continuous electro-galvanising of sheet and strip. The plant consists of a long steel frame with the

following sections: (1) Loading table; (2) feed rollers driven from a shaft running the whole length of the machine; these rollers form the cathode connection of the plant; the top roller is of stainless steel and the lower one of rubber; (3) a series of three or more pickling vats with a rotary scrubber between each pair; (4) two hot washing vats; (5) a series of plating vats; (6) a warm water washing bath; (7) an electrically heated drier; and (8) a passing-out table. The plating vats have horizontal orifices fitted with rubber lips. The particular machine described is capable of galvanising 24 strips, $1\frac{1}{4}$ in. wide $\times$ 22 gauge, running side by side at the rate of about 14 tons per 24-hr. day.

Electrogalvanising. W. Eckardt. (Korrosion und Metallschutz, 1941, vol. 17, Dec., pp. 401–403). After a review of recent publications on the effect of impurities on the corrosion resistance of electrodeposited zinc, the author reports on his study of the production of bright zinc coatings. The results obtained with a great variety of bath compositions, and with different temperatures and current densities, are listed in an extensive table.

Effects of Microstructure on the Galvanising Characteristics of Steel. R. W. Sandelin. (Sheet Metal Industries, 1942, vol. 16, May, pp. 610–614; June, pp. 783–786). The author's paper on the effects of cold reduction, grain size and carburising treatment of low-carbon steel wire on the properties of the coating after galvanising is reproduced. (*See* Journ. I. and S.I., 1942, No. I., p. 103 A).

Experience with Alkaline Zinc Plating. J. S. Jones and P. M. Walker. (Journal of the Electrodepositors' Technical Society, 1942, vol. 17, pp. 155–163). The authors describe the change-over at a British plating works from cadmium plating to alkaline zinc plating. Particulars of the solutions and procedure are given. Chemical control of the bright zinc solution requires more attention than that for cadmium solution. The change from cadmium to zinc for the purpose of rust-proofing parts ranging from small switches to components of very large turbo-generators was successfully accomplished in the manner described.

Zinc Coating on Wire. F. R. Morral. (Wire and Wire Products, 1942, vol. 17, June, pp. 287–290, 314; July, pp. 345–349, 368–371). The author discusses processes of galvanising wire to meet various specification requirements and the possibilities of applying to wire methods which have been used for galvanising material other than wire.

Automatic Zinc Plating as Applied to Strip Coating. B. C. Newlove. (Monthly Review of the American Electroplaters' Society, 1942, vol. 29, May, pp. 408–411). The author briefly describes the equipment required for the continuous zinc plating of steel strip.

Hot Dip Tinning of Carbon Steels as Affected by Variation of Carbon, Phosphorus, Copper, Silicon, Manganese, Aluminum and Titanium. M. E. Fine and R. L. Dowdell. (Wire and Wire Pro-

ducts, 1942, vol. 17, May, pp. 237–242, 256–257; June, pp. 294–299, 320; July, pp. 351–354). The authors describe an investigation of the properties of the tin coating on a series of 63 steels of different composition, the object being to study the effects of changes in the amounts of carbon, phosphorus, copper, silicon, manganese, aluminium and titanium on the smoothness of the coating, its appearance under the microscope, the thicknesses of the tin and iron-tin-compound layers and on the continuity of the coating. All the steels tinned satisfactorily, only small differences in the properties of the coating being observed. A high silicon content caused the coating to be slightly rough. Either high silicon or high manganese tended to increase the thickness of the iron-tin alloy layer. Apart from the above, no other correlation between the composition of the steel and the properties of the tin coating could be established. Thickness determinations of the iron-tin alloy layer revealed that an increase in the silicon or manganese in the steel appeared to increase the thickness of this layer, but no such correlation was observed with tinplate made from rimming steel.

Food in Cans. T. W. Lippert. (Iron Age, 1942, vol. 149, Apr. 30, pp. 29–44). The author reviews the position in the United States with regard to the supply and consumption of tin for making tinplate, the measures taken by the government as to allocation of the reduced amount of available tin and the technical improvements and experiments carried out by various tinplate manufacturers. It is planned to produce 30,000,000 basis boxes of electrolytic tinplate in 1943. Brief particulars of the electrolytic tinning plants at the principal American mills with detailed descriptions of two continuous wide-strip installations are given. One of these is at the Gary plant of the Carnegie-Illinois Steel Corporation; here 32-in. strip is tinned at 350 ft. per min., the strip passing vertically into four tanks in tandem each 5 ft. deep. The second is that of the Crown Cork and Seal Co., Incorporated, Baltimore. This company employs an alkaline solution; the existing tinning line is 120 ft. long and it will handle strip up to 32 in. wide at 375 ft. per min.; additional equipment is being built to take strip up to 36 in. wide at 550 ft. per min.

Substitute Coatings for Tin Plate. C. E. Brown. (Iron and Steel Engineer, 1942, vol. 19, July, pp. 30–33). The author discusses the limitations of various forms of coating which have been suggested as substitutes for tin for the canning industry. The choice appears to be limited to oiling and lacquering, and bonderising. A bonderised coating cannot be soldered, but it is proposed to use bonderised cans for packing products with mildly corrosive properties.

The Influence of Various Factors on the Coating Tin on Tinplate. J. Teindl. (Korrosion und Metallschutz, 1941, vol. 17, Nov., pp. 390–396). The author discusses, in separate paragraphs, the

influence of the following factors on the quality of tinplate and on the quantity of tin required: (1) The rolling procedure; (2) the composition of the base material; (3) the thickness of the plate before coating; (4) the mode of pickling; (5) the normalising process; (6) the polishing technique; (7) the chemical reactions involved in tinplating; (8) the flux used; (9) the characteristics of the tinning-machine rolls; (10) the speed of travel; (11) the quantity of palm oil used; and (12) various mechanical effects of the equipment used.

The Spraying of Metals. W. E. Ballard. (Iron Age, 1942, vol. 149, May 21, pp. 50–54). The author reviews the development of metal-spraying on the Continent, in England and in the United States, with particular reference to sprayed coatings of aluminium. He points out that the tendency in England is to concentrate on obtaining a coating with high corrosion-resistance properties using a wire diameter not exceeding 2 mm., whereas in the United States more stress is laid on obtaining rapid deposition for which thicker wire is required.

Corrosion Protection of Foodstuff Containers by Phosphatising and Lacquering. H. Weise. (Korrosion und Metallschutz, 1941, vol. 17, Oct., pp. 363–365). The author reviews a number of lacquers which have proved suitable for tins for canning fish, meat, cheese and vegetables, but not fruit and acid foodstuffs. He describes various modes of applying these lacquers to black-sheet cans phosphatised by bonderising.

Chromates as Rust-Preventing Paints. H. Wagner. (Korrosion und Metallschutz, 1941, vol. 17, Oct., pp. 341–345). The author discusses the use of lead and zinc chromates in protective paints, especially in combination with other pigments, and develops a theory according to which the effect of the chromates is due, not to passivation, but to a reaction with the vehicle by saponification, which results in increased strength of the films. He reports on favourable practical experiences with lead- and zinc-chromate paints, and points out that increased use of the latter in the place of lead paints would be desirable for economic reasons. The zinc chromate should be mixed with a higher proportion of zinc oxide than is usual at present, however, in order to economise in chromium and to facilitate saponification.

The Pigments in Important Protective Paints. F. von Artus. (Korrosion und Metallschutz, 1941, vol. 17, Oct., pp. 361–363). The author enumerates inorganic and organic pigments suitable for protective paints, especially for those based on a chlorinated-rubber medium.

A Note on Red Lead Economy in Rust-Preventing Paints. P. Prill. (Korrosion und Metallschutz, 1941, vol. 17, Oct., pp. 345–347). The author reports on atmospheric corrosion tests carried out on rolled steel sheet specimens coated with protective paints containing pure red lead and red lead mixed with barytes in various proportions, with ammonia-treated active carbon plus zinc oxide,

and with ammonia-treated active carbon plus micaceous iron ore. The paints with pure red lead and with ammonia-treated active carbon proved greatly superior to those with admixtures of barytes.

PROPERTIES AND TESTS

A Short-Gage-Length Extensometer and Its Application to the Study of Crankshaft Stresses. C. W. Gadd and T. C. van Degrift. (Journal of Applied Mechanics, 1942, vol. 9, Mar., pp. A-15–A-20). The authors describe an extensometer suitable for use on short gauge lengths, and its application for studying stresses in crankshafts. The operation of the gauge is by means of a simple mechanical lever integral with one of the gauge points and a pair of gratings of alternate transparent and opaque bands which intercept a collimated beam of light rays directed on a photocell. The mechanical stage is coupled directly to one of the gratings; the other remains fixed, except when making necessary adjustments prior to applying the load to the specimen and checking a stress. When the specimen is strained the gratings move relative to one another in such a manner that the light falling on the cell varies in proportion to the strain.

Plastic Flow as an Unstable Process. L. H. Donnell. (Journal of Applied Mechanics, 1942, vol. 9, June, pp. A-91–A-95). Instead of occurring simultaneously over regions which are uniformly stressed, plastic flow frequently proceeds in a discontinuous manner, as in the formation of wedge-shaped plastic regions around the periphery of specimens tested in torsion. In this paper the author explains this phenomenon as an instability brought about by stress concentrations which are caused, not by discontinuities in the shape of the specimen, but by the discontinuous behaviour of the material around the yield point.

Correlation of Residual Stresses in the Fatigue Strength of Axles. O. J. Horger and H. R. Neifert. (Journal of Applied Mechanics, 1942, vol. 9, June, pp. A-85–A-90). The authors study and present data relating to the correlation between the residual stresses arising from heat treatment and the fatigue strength of solid and hollow railway wagon axles. It was found that a high fatigue strength was associated with high residual surface compressive stresses, and the lowest fatigue-strength values were associated with residual surface tensile stresses.

Fatigue Strength of Welded Joints. W. Spraragen and D. Rosenthal. (Welding Journal, 1942, vol. 21, July, pp. 297-S–348-S). The authors present a comprehensive review of the literature from October 1936 to September 1941 on the fatigue strength of welded joints. The bibliography contains 127 references.

Hardenability Calculated from Chemical Composition. M. A. Grossmann. (American Institute of Mining and Metallurgical

Engineers, Technical Publication No. 1437: Metals Technology, 1942, vol. 9, June). The author develops a series of curves and data which enable the hardenability of a steel to be calculated from its chemical composition and grain size. (An abridged version of this paper has appeared previously, *see* Journ. I. and S.I., 1942, vol. II., p. 219 A).

Metallic Wear of Metals and Alloys. J. W. Donaldson. (Metallurgia, 1942, vol. 26, Sept., pp. 155–160). After describing the principles of the Amsler and Skoda-Sawin wear-testing machines, the author considers how lubrication, surface temperatures, running-in and polish affect cylinder wear, oxidation wear and the seizure of surfaces. In conclusion, the properties of some wear-resisting materials are given together with curves which show the relation between the surface hardness and the depth of case of steels treated by case-hardening, nitriding and induction hardening.

Notes on the Temperature Coefficient of Resistivity of Metals and Alloys. J. C. Chaston. (Metal Treatment, 1942, vol. 9, Autumn Issue, pp. 71–73). The author points out some facts relating to the changes with temperature of the electrical resistivity of metals and alloys. The resistance of nearly all metals is about 40% greater at 100° than at 0° C.; the exceptions to this generalisation are iron, thallium, cobalt, nickel and rubidium, for which metals the increase in resistivity is about 65%.

The Thermal and Electrical Conductivities of Metals and Alloys. J. W. Donaldson. (Metal Treatment, 1942, vol. 9, Autumn Issue, pp. 97–107). The author reviews recent investigations of the thermal and electrical conductivities of pure metals and alloys and the relationship between the two conductivities as given by the Wiedemann-Franz-Lorenz law. For certain ferrous and non-ferrous alloys curves have been obtained from which experimental values do not depart by more than a given percentage, usually 10–12, and from these curves equations have been derived for estimating the thermal conductivity from the electrical conductivity.

The Behaviour of Steel at Elevated Temperatures. A. Pomp. (Stahl und Eisen, 1942, vol. 62, July 2, pp. 571–575). The author reviews the German and American literature published in 1941 on the properties of steel at high temperatures.

Hardenable Alloys as Wear-Resisting Materials for Deposition by Welding. P. Ehlers. (Autogene Metallbearbeitung, 1940, vol. 33, Dec. 1, pp. 301–304). The author describes the properties and applications of an iron-base alloy for hard-facing containing carbide-forming elements and up to about 3·5% of carbon which has been developed by the I. G. Farbenindustrie. It is known as "Gridur E." It has good welding properties and can be hardened by heat treatment to Rockwell C 65 and even higher.

Economy in the Use of Ferro-Alloys. W. H. Hatfield. (Metallurgia, 1942, vol. 26, Sept., pp. 149–151). This paper constitutes the author's address at the Conference on Mineral Resources and the

Atlantic Charter, held recently by the Social and International Relations of Science Division of the British Association. From a review of the geographical position of raw materials it is seen that the principal steel-producing countries are dependent on the normal functioning of international trade and copious transport, particularly shipping. In 1940, the Special and Alloy Steels Committee set up a Technical Advisory Committee to deal with the problem of reducing the number of specifications for steel and the 2000–3000 existing specifications were sorted out into 85 categories, mainly on the basis of mechanical properties, compositions or special functions. From these categories the British Standards Institution selected and published 58 specifications in B.S. 970/1941 which was revised in 1942. In conclusion the use of small amounts of alloying elements, such as chromium and nickel, to render possible the hardening and tempering of steel of heavy section is briefly discussed.

New Metals and New Methods. C. H. Desch. (Nature, 1942, vol. 150, Oct. 10, pp. 419–421). This is a paper read at the Conference on Mineral Resources and the Atlantic Charter arranged by the Division for the Social and International Relations of Science of the British Association. The author discusses the effects of elements of rare occurrence on iron and steel, the development of new alloys, methods of processing new alloys and their applications, and the difficulties of substituting one metal or alloy for another.

New Aero (NE) Steels. (Steel, 1942, vol. 111, Sept. 7, pp. 78–82). As part of the plan for formulating the specifications of the National Emergency Steels in the United States the Technical Advisory Committee on Aeronautical Steels was set up, and this committee has drawn up a tentative list of carbon, low-alloy and corrosion-resistant steels covering bars, sheets and tubing which it is thought should provide all the needs of aircraft manufacturers. The compositions of these steels, with their tentative numbers and data on the steels they are intended to replace, are given in two tables.

Available Steels for the Petroleum Industry under Present Emergency Conditions. A. Grodner. (Steel, 1942, vol. 111, Aug. 17, pp. 73–74). The author gives a summary of some of the alloy and carbon steels still available to the petroleum industry in the United States, classifying them according to their corrosion resistance at normal and at elevated temperatures and their strength at low temperatures, and giving the A.S.T.M. code numbers.

National Emergency Gear Steels. E. F. Davis. (Iron Age, 1942, vol. 150, Aug. 6, pp. 45–49; Aug. 13, pp. 58–64). The author describes how the American Iron and Steel Institute in collaboration with the Society of Automotive Engineers drew up the specifications of National Emergency Steels, and then gives details of the composition and properties of those of the NE 8000 series which fall into two general groups, the manganese-molybdenum and the chromium-nickel-molybdenum steels. In the second part

of the paper the microstructure and hardenability of the S.A.E. 4000 series of steels, with particular reference to gear making, are discussed. The only alloying element in these steels is molybdenum, the amount present being 0·20–0·30%. They are not actually National Emergency Steels, but are recognised by both the above institutions.

The National Emergency Steels NE 8000 Series. C. M. Parker. (American Iron and Steel Institute, Contributions to the Metallurgy of Steel, No. 7, 1942). Particulars are given of the properties, especially the hardenability, of National Emergency Steels of the 8000 series, which are manganese-molybdenum and chromium-nickel-molybdenum steels.

Supplementary National Emergency Steels NE 9400, 9500 and 9600 Series. (American Iron and Steel Institute, Contributions to the Metallurgy of Steel, No. 8, 1942). This publication constitutes a report by the Technical Committee on Alloy Steel of the American Iron and Steel Institute to the War Production Board in which the development of three new types of National Emergency Steel is described and their properties, especially hardenability, discussed. The NE 9400 series are manganese-silicon-nickel-chromium-molybdenum steels; the NE 9500 series are manganese-silicon steels with 0·40–0·60% each of nickel and chromium, plus 0·15–0·25% of molybdenum; the NE 9600 series are manganese-silicon-chromium steels.

Selection and Conservation of Alloying Elements Used in Steel. J. Mitchell. (American Iron and Steel Institute, Contributions to the Metallurgy of Steel, No. 6, 1942). The effects of small quantities of the elements carbon, manganese, phosphorus, sulphur, silicon, chromium, nickel, molybdenum, vanadium and copper in steel on the abrasion resistance, fabricating properties, machinability, quench-crack sensitivity, corrosion resistance, strength and toughness are discussed. The information given is also presented in a table in which the beneficial or detrimental effects are indicated by a simple code.

Guide to Alloying Elements Used in Steel. (Iron Age, 1942, vol. 150, Aug. 6, pp. 56–57). A summary of the information given in Contributions to the Metallurgy of Steel, No. 6, is presented. (*See* preceding abstract).

Conserving Alloy Steels. C. L. Clark. (Steel, 1942, vol. **111**, Sept. 7, pp. 111, 123–125). The author presents data on the corrosion resistance and creep strength of steels containing different amounts of chromium with particular reference to steels containing a minimum amount of chromium which would be suitable for plant for refining and cracking oils.

The En Steels in Peace and War. (Iron and Steel, 1942, vol. 15, Aug., pp. 411–416; Sept., pp. 443–446). The properties of the "En" steels are discussed from the point of view of their suitability for light, but high-duty, machinery, including aero-engines.

The " En " steels are the 58 steels for general engineering purposes selected by the Technical Advisory Committee of the Iron and Steel Control which are included in the War Emergency Standard Schedule 970–1941.

Metallurgical Study of Cast Iron for Glass Molds. W. H. Bruckner and H. Czyzewski. (Journal of the Ceramic Society, 1942, vol. 25, Sept. 1, pp. 381–388). The authors report the results of research the object of which was to develop an iron suitable for the moulds in automatic glass-forming machines. The difficulty is to prevent cracks from forming in that part of the surface which is alternately heated and cooled by the hot glass and its removal. An accelerated method of testing was devised. The results indicated that sand-cast iron is more resistant to cracking than chill-cast iron of the same composition. Annealing chill-cast alloy irons increases the resistance to cracking, whereas a spheroidising heat treatment decreases it. The most suitable material appears to be an annealed chill-cast alloy iron containing chromium, nickel and molybdenum; this iron is more susceptible to cracking than a sand-cast iron of the same composition, but the latter will not polish sufficiently.

CORROSION OF IRON AND STEEL

Electrolysis Corrosion. (Journal of the Institution of Engineers Australia, 1942, vol. 14, June, pp. 148–150). This article is a reproduction of Corrosion Circular No. 5 issued by the Council for Scientific and Industrial Research; it is in two parts. The first part describes methods of preventing the electrolytic action which accelerates the corrosion of underground metallic structures such as petrol and oil storage tanks and related pipework. " Cathodic protection " may be applied to petrol pumps and similar structures, as well as pipes, by forcing a direct current to discharge from an earth plate and to collect on the metal surface to be protected. The second part deals with precautions against stray-current corrosion of buried metal conduits by contact with bridge structures; in this part methods of insulating the conduits from the structure to which they are fastened are described.

A Study of Soluble Inhibitors, with Special Reference to Heat Transfer and Water-Line Attack. R. S. Thornhill and U. R. Evans. (Journal of The Iron and Steel Institute, 1942, No. II., pp. 73 P–103 P). In the first part of the paper U. R. Evans in an explanatory statement indicates the problems which the research described in the second part was intended to solve. The tests were made by alternately heating and cooling 6-in. specimens of steel strip; the ends of the specimens were bent over and dipped into (*a*) softened water, (*b*) untreated water and (*c*) untreated water containing magnesium chromate. He discusses the purposes

of an inhibitor and summarises the conclusions which may be drawn from the investigation of the behaviour of magnesium chromate under different conditions, an account of which is given by R. S. Thornhill in Part II. The latter carried out experiments to ascertain whether magnesium chromate belongs to the "safe" or the "dangerous" class of inhibitors. Tests upon steel partly immersed in various natural waters under conditions of alternate heating and cooling indicate that, if rusting is to be avoided, magnesium chromate must be replenished at certain intervals. But even if the periods elapsing between replenishments are double those needed to avoid all corrosion, the steel suffers little thinning over periods sufficient to cause perforation of steel in similar water without chromate. In cases where steel was allowed to start rusting before the inhibitor was added, the rusting ceased after the addition of the inhibitor. On the other hand, experiments without heating under stagnant conditions showed that steel carrying mill-scale interrupted by a scratch-line suffered more rapid thinning when inadequate amounts of the inhibitor were added than in similar water without inhibitor. Both potassium chromate and basic magnesium chromate decrease the total corrosion as the amount added is increased, but the intensity of attack, owing to localisation, is at first greatly increased. Thus, both of the inhibitors belong to the dangerous class.

The intense localised corrosion which occurs at concentrations intermediate between those permitting general corrosion and those conferring complete immunity sometimes takes the form of pitting. It may occur on any part of the specimen, but when the susceptible point is situated in or near the meniscus zone, the attack develops into a "box" of triangular cross-section, instead of the ordinary blister, and under these water-line conditions the attack is very vigorous. The fact that the water-line may sometimes be immune and sometimes specially attacked, according to the nature of the metal, the liquid and the time of exposure, is capable of a consistent explanation. Another cause of water-line attack has been found in the condensation of moisture, free from inhibitor, above the water-line; where this trickles down, it produces an area locally weaker in inhibitor, giving rise to the cell:

Iron | Concentrated inhibitor | Diluted inhibitor | Iron.

Measurements of heat transfer through steel walls show that under conditions where the corrosion product would cling to the walls and obstruct heat transfer, the presence of basic magnesium chromate improves the situation by preventing the formation of that corrosion product. However, in the waters studied, the corrosion product does not cling to the walls under conditions of alternate heating and cooling, so that in effect the presence of the inhibitor has little influence on heat transfer.

Cans Made of Bonderised and Lacquered Steel Sheet. L. Schuster. (Stahl und Eisen, 1942, vol. 62, Aug. 13, pp. 685–694).

Bonderised and lacquered cans are now being used for preserving foods and have been developed to an important extent. In this paper the author presents and discusses the results of tests in which a comparison was made of physical and corrosion-resistance properties of lacquered cans the steel for which was treated by bonderising and other methods before being lacquered. These tests proved that bonderising fulfills the requirements by providing good adhesion for the lacquer and considerably increasing the corrosion resistance. The best results were obtained with a very light and fine-grained bonderised coating. A plant for bonderising and lacquering 5000 to 6000 cans per hr. is described.

Rust-Proofing Cadmium Plated Aircraft Tubular Parts. B. Gross. (Iron Age, 1942, vol. 150, July 30, pp. 52–53). The author describes some corrosion tests on cadmium-plated chromium-molybdenum steel tubes used in aircraft construction. It was found that when the tube was hermetically sealed by welding, both the inside and outside surfaces were in perfect condition after an 800-hr. salt-spray test. When the inside of the tube was flushed with hot linseed oil, drained, and the holes plugged with cadmium-plated screws, internal corrosion began after only 24 hr. in the salt spray and the external coating was also attacked.

Corrosion Tests on Welded and Annealed Specimens. L. Hunsicker. (Autogene Metallbearbeitung, 1941, vol. 34, Sept. 1, pp. 273–280). The author reports on an investigation of the rates of corrosion and the changes in tensile strength and elongation of specimens of steel, copper and aluminium in continuous and in intermittent immersion tests lasting 250 hr. Special attention was given to the effect of scale. The surface potential of scale-covered material was determined from the potential of the scale and that of the metal underneath. The more scale present and the tighter its adherence to the metal, the nearer did the surface potential approach that of the scale. The uniform coating of scale caused by annealing lowered the surface potential. In continuous immersion tests on a scale-covered specimen from the heat-affected zone of a weld, the rate of corrosion decreased rapidly with time in the early stages, whilst the rate of corrosion of machined scale-free specimens of weld metal varied between two limiting values and, generally speaking, was greater than that of metal from the heat-affected zone. In intermittent immersion tests with machined and with scale-covered specimens the specific rates of corrosion decreased at first, but after a certain lapse of time they increased rapidly; the fine-grained material annealed at a higher temperature corroded the least. With cast iron the specific rate of corrosion increased rapidly at first, then decreased equally rapidly and finally progressed at a steady rate.

Water Immersion Testing of Metal Protective Paints. W. W. Kittelberger. (Industrial and Engineering Chemistry, Industrial Edition, 1942, vol. 34, Aug., pp. 943–948). The author reports

the results of corrosion tests in which seven series of 4 in. × 6 in. steel panels were painted using seven well-known linseed-oil paints. There were six panels in each series. After drying for three weeks each set of six was prepared so that two panels were completely coated on both sides, two had bare metal areas of about 1 sq. mm. and two had bare metal areas of about 78·5 sq. mm.; these bare areas were in the centre of one side. All the panels were immersed to a depth of 4 in. for 32 days, one lot in tapwater and a second lot in a 3% solution of sea salt. The salt water was changed once a week and observations of blistering and rusting were made at intervals; finally, the paint was removed and the panels were graded for corrosion. The effect of the bare metal areas on the order of quality of the seven paints was practically negligible in the case of blistering and rusting in tapwater and rusting in salt water. Graded by blistering in salt water, the order of merit of the paints on fully coated panels differed from that of panels with bare areas.

The results demonstrated that, in evaluating the protective properties of organic coatings by salt-water immersion tests, a lack of control over the areas of bare metal may lead to serious errors; in the tests described an area of 1/1200th of the painted immersed area had a marked influence.

MINERAL RESOURCES

(Continued from p. 1 A)

Mineral Resources of the U.S.S.R. D. Williams. (Nature, 1942, vol. 150, Nov. 7, pp. 539–541). This paper constitutes the author's address at the Conference on Mineral Resources and the Atlantic Charter, held recently by the Social and International Relations of Science Division of the British Association. Even omitting the astronomical tonnages of low-grade quartzitic iron ores of the Kursk district, the Soviet reserves of iron ore have recently been estimated at more than 10,000 million tons, surpassing those of the United States. With such huge resources it is clear that the Soviet Union has the opportunity not only of fulfilling her own internal demands, but also of contributing a generous export supply. In 1936 the manganese resources of the Union were computed at more than 700 million tons. Although the output of chromite has increased during the past decade, it has latterly been used almost wholly for domestic requirements of ferro-chromium and chromium chemicals. Unless fresh discoveries are made, Russia may feel compelled to retain her entire production of chromite for home consumption. For tungsten and molybdenum the Union relies very largely on imports. By exploiting several extensive low-grade nickel-silicate deposits in the Urals and nickel-sulphide bodies in the Kola Peninsula and in Northern Siberia, the Union may well become independent of imports in times of peace.

Brazil. E. A. Teixeira. (Engineering and Mining Journal, 1942, vol. 143, Aug., pp. 89–98). In this description of the mineral resources of Brazil the author shows that there are very large reserves of iron, manganese and nickel ores. The deposits of high-grade iron ores in Minas Geraes alone are estimated at 1,500,000,000 tons. Fourteen smelting plants are in operation, and in 1939, 160,000 tons of pig iron and over 100,000 tons of steel were produced. Manganese deposits are found in three States in Brazil, all far from the coast. The Morro da Mina mine in the Minas Geraes is the most important, producing about 20,000 tons of ore per month. The ore as put on rail contains about 46% of manganese and 7% of iron. The nickel ore garnierite occurs in minable quantities in the States of Goyaz and Minas Geraes, but the Goyaz deposits have not been successfully worked because they are too far from any railway or seaport. At Livramento in Minas Geraes a 20-ton electric furnace is being used to produce 20% ferro-nickel.

Chile. F. Benitez. (Engineering and Mining Journal, 1942, vol. 143, Aug., pp. 75–80). The author gives an account of the mineral resources and present state of development of mining in Chile. The principal metals and minerals produced and the esti-

mated output at the present time are: copper 500,000 tons, iron ore 1,750,000 tons, manganese ore 60,000 tons, molybdenum concentrate (90% MoS_2) 1000 tons, coal 2,200,000 tons and sodium nitrate 1,500,000 tons. There are iron-ore deposits all less than 20 miles from the coast, the best known being a little north of the port of Coquimbo; this ore contains iron 60%, phosphorus 0·05% and silica 7·5%.

Venezuela. N. B. Knox. (Engineering and Mining Journal, 1942, vol. 143, Aug., pp. 85–88). The author gives an account of the mineral resources of Venezuela. Apart from gold, the principal minerals now under development are iron ore, asbestos, and magnesite; mercury and chromite have also received some attention. Although the immense tonnage of iron ore available in the Imataca Range has never been measured, some exploration and development work has been done, principally at El Pao. This bed is estimated at over 60,000,000 tons of ore containing 65% of iron. A harbour is being constructed at Palua on the Orinoco River 30 miles away, and this will eventually be connected to the mines by railway.

ORES—MINING AND TREATMENT

Some New Experiences Relating to Drilling and Blasting in Mining. T. Ekstam. (Jernkontorets Annaler, 1941, vol. 125, No. 8, pp. 441–466). (In Swedish). The author describes developments in drilling and blasting as practised in the iron-ore fields of North Sweden. The advantages of hammer drilling machines and of having detachable bits on the drill-rods are discussed and data are presented which enable drilling times and costs to be compared. The techniques for placing explosives and shot-firing are described.

Investigation of the Possibilities of Reducing the Weight of Hoist Ropes Used in Ore Mining. E. Rothelius. (Jernkontorets Annaler, 1941, vol. 125, No. 11, pp. 615–650). (In Swedish). In the first part of the paper the author presents a mathematical analysis of the factors affecting the weight of the wire ropes used for hoisting in iron-ore mines. The most important factors are the breaking stress of the rope, the safety factor and the dead load. In the second part mining experience and accident statistics and their relation to these factors are dealt with. To increase the breaking stress is the simplest way of decreasing the rope weight, but experience has shown that to increase this above 150 kg. per sq. mm. means shortening the rope life.

The Changes in Phosphorus Content when Concentrating some Swedish Iron Ores with a Shaking-Screen Plant. F. Mogensen. (Teknisk Tidskrift, 1941, vol. 71, Aug. 9, Bergsvetenskap pp. 61–68). (In Swedish). The author reports on an investigation of the distribution of phosphorus in the screenings at a plant for con-

centrating Swedish iron ore. It was found that as soon as apatite was present in a fairly pure crushed state a belt of apatite formed itself behind the iron-ore belt on the shaking screen and this was often the cause of high phosphorus in the "slig" (an ore concentrate high in iron).

Heat Balances and Economics of Ore-Preparation Plants. III. Present Problems in the Preparation of the Burden, especially Sintering. K. Guthmann. (Stahl und Eisen, 1942, vol. 62, Aug. 6, pp. 671–677). Having discussed the importance of adequate crushing, grading and mixing facilities for iron ores in Part II. of this series (*see* Journ. I. and S.I., 1942, No. II., p. 89 A), the author in Part III. considers the economic aspects of ore preparation, dealing in particular with the results obtained when sintering with different fuels, the effects of different proportions of sinter in the burden on the coke consumption in the blast-furnace, the present state of development of ore-preparation plants and the demand for structural steel to build them.

FUEL

(Continued from p. 3 A)

High-Pressure Steam and Boiler Plants in Iron and Steel Works W. Güldner. (Stahl und Eisen, 1942, vol. 62, Oct. 1, pp. 835–843). The author discusses the steam economy of iron and steel works and the points which must be considered in connection with the installation of high-pressure steam plant at a steelworks. For the efficient production and use of steam high temperature and high-pressure technique must be applied. Increasing the temperature has relatively more effect than increasing the pressure. The steam temperature is to-day limited to about 500° C. by the durability of materials. The steam economies of seven different works are compared and it is seen that the results achieved differ greatly. It is recommended that for the future an effort to standardise boilers should be made.

Recent Advances in the Control of Multi-Fuel-Fired Furnace. V. C. Vaaler. (Iron and Steel Engineer, 1942, vol. 19, Sept., pp. 134–138). The author gives details of mechanisms which have been devised for controlling the fuel and air supply to open-hearth and reheating furnaces burning more than one fuel. These control systems have been devised to solve such problems as: (1) Total air-flow control with automatic flow control of the primary fuel and manual control of the secondary fuel; and (2) total heat-input control with a varying supply of primary fuel and make-up of secondary fuel with a superimposed temperature control.

Efficient Operation of Heating Furnaces. F. A. Gray, R. J. Sarjant and H. H. Utley. (Fuel Economy Review, 1942, vol. 21,

pp. 16–39). The authors present a treatise on furnace practice and outline the essential features of the economical operation of heating furnaces. The chief properties and uses of natural and prepared fuels are dealt with first. The theory of combustion and the method of selected fuel is dealt with next. This is followed by a discussion of the main elements of furnace design and how to avoid unnecessary losses of heat. The last three sections of the treatise relate to obtaining a general idea of the efficiency of a furnace plant, auxiliary plant and whether it is possible to improve the efficiency of a furnace when rebuilding it.

Experience in the Coking and Low-Temperature Carbonisation of Saar and Lorraine Coals. W. Gollmer. (Stahl und Eisen, 1942, vol. 62, Sept. 17, pp. 789–795). The author gives an account of trials with several processes the object of which was to develop an economic method of coking Saar and Lorraine coals. These trials brought to light hitherto unrecognised properties of the coals, but a satisfactory method of avoiding having to bring in a suitable non-caking diluent (such as ground coke breeze) from a considerable distance to mix with the coke-oven or retort charge was not found.

Fundamental Considerations Concerning the Improvement of Blast-Furnace Coke. H. Hoffmann. (Stahl und Eisen, 1942, vol. 62, Oct. 1, pp. 846–849). The author discusses methods of determining the suitability of coke for reducing ore in the blast-furnace. He describes briefly some of the well-known methods of testing cokes and points out that these do not give a full picture of the surface structure of coke so as to enable the behaviour of the coke in the blast-furnace to be reliably predicted. Some methods for improving the quality of coke made from Saar and Upper Silesian coals are described.

The Selection of Bituminous Coals for Use in Gas Producers. (Fuel Economy Review, 1942, vol. 21, pp. 74–81). In an earlier article on gas-producer practice (*see* Journ. I. and S.I., 1942, No. I., p. 6 A) a section was included on the selection of suitable bituminous coals. In the present paper specific data on the properties of suitable coals from the various coalfields of Great Britain are made available. This information has been supplied by the following authors :

J. Gibson : Ayrshire and Dumfriesshire Coals.
J. A. C. Edmiston : Lanarkshire and Lothian Coals.
R. Bulmer : Northumberland and Durham Coals.
R. A. Mott : Yorkshire, Derbyshire and Nottinghamshire Coals.
H. T. Pinnock : South Midland Coal.
F. J. Hurlbut : Coals Used in Lancashire.

Gas Producer Calculations. (Fuel Economy Review, 1942, vol. 21, pp. 67–68). In amplification of an article "Notes on the Efficient Working of Gas-Producer Plant" (*see* Journ. I. and S.I.,

1942, No. I., p. 6 A) methods of obtaining data which provide a useful insight into the quantitative aspects of the principal reactions taking place in the fuel bed of a producer are now published. Methods of calculating the carbon balance and the nitrogen balance are explained.

PRODUCTION OF IRON

(Continued from pp. 3 A–6 A)

Instruments for Aiding Blast Furnace Production. R. M. Walker. (Steel, 1942, vol. 111, Sept. 14, pp. 134–142, 192–197). The author describes several types of instruments and control systems used in blast-furnace practice, including those for recording the temperature, pressure, humidity and flow of the blast, stock-line recorders, shaft temperature recorders and stove temperature recorders. Experiments are being carried out with a photoelectric instrument for recording the grains of dust per cubic foot in the top gas entering the dust catcher.

Dry Blast Production. D. Wolochow. (Canadian Metals and Metallurgical Industries, 1942, vol. 5, Aug., pp. 230–237). The author reviews the literature on the drying of blast-furnace blast by chemical means and by refrigeration, and cites and compares the results achieved in American, Canadian and English practice.

Different Methods of Producing Vanadium Slag. H. Zieler. (Stahl und Eisen, 1942, vol. 62, Sept. 17, pp. 795–799). The recovery of the vanadium usually present in the iron ores used in Germany has become of great importance and the majority of the German basic-Bessemer steelworks use a vanadium-rich pig iron and slag-off the vanadium with this purpose in view. In this paper the author reviews and compares the vanadium-recovery processes of several German works.

Slag Systems—The Viscosity Determination of Blast Furnace Slags. R. Hay. (Journal of the West of Scotland Iron and Steel Institute, 1941–42, vol. 49, Part VI., pp. 89–99). A short account of some preliminary work on slag viscosity determinations has been published previously (*see* Journ. I. and S.I., 1938, No. I., p. 60 A). In the present paper the results of some further work using the concentric cylinder method are given. The apparatus consisted essentially of two concentric cylinders surrounded by an electric furnace; the slag was placed between the cylinders and the torque from the inner cylinder rotated under a constant couple caused by the fixed outer cylinder was measured. This apparatus is described in detail and the formulæ used in the calculations are explained. From many experiments with synthetic blast-furnace slags the following conclusions are drawn: (1) When there is no change in the mineral constituents of a slag, the viscosity varies continuously with the composition; but when a change in the mineral constitu-

ents occurs, the viscosity-composition curves show decided discontinuities, these corresponding to the composition at which the new constituent appears. (2) The viscosity-temperature curves tend to become asymptotic at temperatures considerably above the melting point of the various melts, and this suggests that, with increasing temperature, dissociation increases so that at sufficiently high temperatures, viscosity will change continuously with composition. (3) Working with a slag of the normal basicity of 1·4, ores with 20–30% of alumina can be used to produce high-silicon iron suitable for foundry practice, but if a basic iron is required, then it is essential to have a lower hearth temperature to prevent the reduction of silica to silicon ; an alteration in the type of slag is therefore essential to get a reduced viscosity, otherwise scaffolds and similar troubles will be experienced. This reduction in viscosity may be achieved by increasing the silica content of the slag. (4) Fluorspar has been shown to reduce the viscosity of certain melts, and has been used in practice to remove scaffolds. (5) Magnesia has also been shown to reduce the viscosity of $CaO–Al_2O_3–SiO_2$ melts.

Methods of Producing Metals and Ferro-Alloys Having Regard to Swedish Conditions. Bo Kalling and A. Lindblad. (Jernkontorets Annaler, 1941, vol. 125, No. 8, pp. 333–421). (In Swedish). The authors present a comprehensive review of the methods of producing ferro-silicon, silico-aluminium, ferro-manganese, spiegel, silico-maganese, ferro-chrome, ferro-tungsten, ferro-molybdenum, ferro-vanadium, ferro-titanium, silico-calcium and ferro-phosphorus as well as the non-ferrous metals aluminium, magnesium, zinc, lead, copper, nickel, cobalt and tin. Attention is given chiefly to the processes used in Sweden and Norway, and those in use in other countries which might later be introduced into Sweden.

The Manganese Requirements of the Steel Industry and a New Metallurgical Method of Concentration. H. Löfquist. (Jernkontorets Annaler, 1941, vol. 125, No. 4, pp. 147–183). (In Swedish). The author first reviews the history of the production of manganese, the importance of manganese in the steel industry, manganese-bearing ores and their geographical distribution, the difficulty in obtaining the ores during the war of 1914–18, and the steps taken in Germany and the United States to improve the manganese position. He then describes in detail the theoretical basis, laboratory and full-scale tests and the scheme for production on an industrial scale, of 50% ferro-manganese by a process developed by himself. This is a method of enriching the spiegel produced from low-manganese ores. The spiegel (containing 20% manganese) is treated in a mixer with a slag low in SiO_2 and high in FeO to which is added FeS in the form of magnetic pyrites or molten FeS_2 and iron scrap. The quantity and composition of the slag are so adjusted that the manganese in the spiegel is slagged off, leaving about 3–5% of manganese in the molten iron. This easily melting ($<1300°$ C.) sulphide-oxide slag can readily be tapped off after a very short reaction lasting only

10 min., and it contains 50–60% of manganese, 2–4% of iron, 10–18% of sulphur and is low in silica. After roasting in a kiln or sintering pan, a sinter containing 53–64% of manganese, 5% max. of iron and low in silica is obtained which can be used for making ferro-manganese in a blast-furnace or electric furnace. The 4–5%-manganese iron left after tapping the slag contains 0·02–0·04% of sulphur, and can be refined in a basic open-hearth furnace to produce a steel containing 0·3–0·4% of manganese; this part of the process gives rise to a slag low in silica, containing 15–30% of iron and 30–40% of manganese, which can be used as an oxidising addition together with iron sulphide to make up a fresh charge. There is thus almost 100% recovery of the manganese. Nearly all the phosphorus is in the iron, and there is practically none in the high-manganese slag. There is also the possibility of utilising certain steelworks' waste products for making up the slag. For instance, when the waste pickling solutions are neutralised with lime, the iron hydroxide and calcium-sulphate sludge which is formed can be utilised. The method described has proved satisfactory in tests at German and American steelworks.

The Practice of Powder Metallurgy. H. W. Greenwood. (Metal Industry, 1942, vol. 61, Oct. 30, pp. 279–281). The author reviews recent literature on powder metallurgy. Reference is made to some experimental work by F. C. Kelley on iron, cobalt, nickel and alloys of these metals. His conclusions were: (1) Pressure is the least important factor, but there is an optimum pressure range which facilitates the obtaining of maximum density (this range for iron and nickel, is 30–60 tons per sq. in., but for cobalt is 10–40 tons per sq. in.); (2) temperature is the most important factor, the critical temperature lying between 1350° and 1400° C.; and (3) time at the required temperature is an important factor; the best sintering time for these three metals is 32 hr.

Julius Römheld, the Builder of the First Coke Blast-Furnace in the Rhine-Westphalian Industrial District. H. Mertens. (Stahl und Eisen, 1942, vol. 62, Oct. 22, pp. 903–905). An account is given of the life and work of Julius Römheld (1838–1904), who in 1847, as blast-furnace manager of the Friederich-Wilhelms-Hütte, Mülheim, made the first attempt in that district to smelt iron ore with coke. This proved to be quite successful. He established an iron foundry of his own in 1859, which he expanded considerably during the next forty years of his life.

FOUNDRY PRACTICE

(Continued from pp. 6 A–9 A)

Fuel Conservation in Brass and Iron Foundries. F. Hudson and A. E. McRae Smith. (Institute of British Foundrymen: Foundry

Trade Journal, 1942, vol. 68, Nov. 5, pp. 209–214). The authors make recommendations for fuel economy in brass and iron foundries. The following general recommendations are made: (*a*) The amount of any individual melt should be as large as possible. (*b*) The bed should be made incandescent as soon as possible and, on completion of charging, a long period should be allowed for soaking the charges to ensure maximum preheating of the initial metal. (*c*) During melting, the cupola should be kept full to the level of the charging door. (*d*) All coke and metal charges should be accurately weighed. (*e*) Adequate steps should be taken to recover as much of the residual bed coke as possible after each blow. (*f*) Excessive poking of the tuyères to free them from frozen slag should be discouraged. Some suggestions for economical mould and core drying are also made.

Cupola Practice with Briquettes. W. A. Hambley and K. Geist. (Iron Age, 1942, vol. 150, Aug. 27, pp. 39–42; Sept. 3, pp. 61–63). The authors give an account of the manufacture of briquettes from cast-iron borings and steel turnings and their use in the cupola at the foundry of the Allis-Chalmers Manufacturing Co., Milwaukee. In the foundry machine shops 600 tons of borings and over 1000 tons of steel turnings are available per month. A variety of cast irons is used, but the borings are all mixed, and the average analysis remains fairly constant at silicon 1·75% and carbon 3·30%. The steel chips and turnings are kept separate in 13 classes of alloy steel which are sold to other users. The chips of unalloyed steel are divided into two classes, the heavy and the light. The dust is removed from the cast-iron borings before briquetting; these briquettes are $4\frac{3}{8}$ in. in dia. and $3\frac{1}{2}$–4 in. high; they weigh 9–12 lb. each and have a density of 85–87% of that of solid cast iron of the same size. There are two briquetting presses each capable of producing 70–75 tons of cast-iron briquettes in 24 hr. Smaller dies are used for pressing steel turnings, and these briquettes have a density of 67–72% of that of solid steel of equal size. The output for steel is 38–40 tons per press in 24 hr.

A wide variety of iron is made at this foundry, and the cupola charges may contain anything from 10% to 85% of briquettes. The operators prefer this to any other form of scrap because of the uniformity of the iron tapped. The first four or five charges on the bed contain no briquettes in order to reduce the smoke nuisance caused by the oil which they contain. The oil in the briquettes does not affect the analysis of the product, and the proportion of rejects has not increased since the charging of briquettes was commenced. The cupola practice using briquettes for making various types of iron is described.

Develops Cupola Mixing Spout. W. A. O'Brien. (Foundry, 1942, vol. 70, Sept., pp. 104, 107). The author describes a special type of spout which facilitates the addition and mixing of alloying elements, desulphurising agents or other additions, with molten cast iron as it leaves the cupola and before it enters the ladle. The

spout is designed with a number of baffles and turns, the object of which is to fold over the stream of iron on itself. The addition agents fall in a steady stream on to the metal at the cupola end of the spout, and the folding action described ensures intimate mixing.

Thermal History of Cast Iron. M. Fielden. (Iron and Steel, 1942, vol. 16, Oct., pp. 2–4). The author discusses factors affecting the cupola process. Experience has shown that the shallow coke charges previously recommended are not only unnecessary, but are also less satisfactory than relatively deep charges. A theoretical depth of 8–10 in., or even more, is now considered to provide a better massing of fuel and, consequently, a greater thermal intensity in the average conditions existing across the area of the melting zone, than is obtained with small charges. Based on data collected from the results of continuous tapping operations which apply in general to the production of repetition castings, it can be stated that with coke of 88–90% fixed carbon value, the combustion rates which provide the most satisfactory performance range between 160 and 200 lb. per sq. ft. of melting zone area per hour. The higher rate is limited where unusually economical practice is found compatible with hot iron, as applies to cupolas with certain refinements. Where it is necessary to have tuyères in more than one plane, the total area of the upper tuyères should not exceed about 20% of the total tuyère area. In general, castings should be poured as hot as the conditions permit, and the characteristics of moulding or facing sand should be adapted to the pouring temperature. Cupola slags to be effective must carry a lime content in excess of the silica to be fluxed. The viscosity of a slag at the temperature existing in normal practice is of greater importance than the melting point. It is essential to good practice that greater care in regard to weight of fluxes should be taken than is generally the case. The coke-consuming reaction represented by the calcination of limestone to lime is, in a narrow economic sense, on the debit side, but the final results as expressed by the casting properties of the iron and the clean condition of the metal more than balance the cost factor.

Malleable Foundry Keeps 'Em Rolling. P. Dwyer. (Foundry, 1942, vol. 70, Sept., pp. 84–86, 161–163). The author gives a description of the plant and processes at the foundry of the Malleable Iron Fittings Co., Branford, Connecticut. This company was founded in 1864, and the present annual output is 5000 tons of steel castings and 9500 tons of malleable iron castings. A very modern conveyor system is installed ; four trains each with eighteen plates or mould-holders and one small electric locomotive carry the moulds ; this arrangement permits the train to halt temporarily at the moulding station, the pouring station and in the cooling tunnel. There are two elliptical tracks with two trains on each, and each train makes 88 circuits per day. The entire cycle is controlled automatically and, if necessary, the speed may be set in advance to meet variation in the mould production unit. The melting equip-

ment consists of two 42-in.-dia. cupolas, and a 16-ton air furnace fired with pulverised coal. The cupolas are operated on alternate days, and supply the metal to the air furnace where it is refined and held at 2800° F. Iron is tapped intermittently from the air furnace and flows into 250-lb. ladles suspended from monorails leading to the pouring stations.

Steel Castings by the Triplex Method. A. W. Gregg. (Iron Age, 1942, vol. 149, May 7, pp. 61–63). The author gives a brief description of a method of producing low-carbon steel for castings; this involves a combination of the cupola, side-blown converter and electric furnace. The cupola charge usually consists of steel scrap plus silicon-bearing material such as 50% ferro-silicon, silicon briquettes or silvery pig iron. The cupola metal is desulphurised in the ladle before blowing. Ordinarily the steel is deoxidised and recarburised by additions of cupola metal, ferro-manganese, ferro-silicon and aluminium before it is delivered to the electric furnace; the latter then acts as a heated distributing unit, and the power consumption is very low. Another method is to dephosphorise the steel from the converter in the ladle by treatment with a combination of lime, fluorspar and mill-scale; the metal is then in a highly oxidised condition, and requires deoxidising in the electric furnace. The above method of dephosphorising is that described by G. M. Yocom (*see* Journ. I. and S.I., 1941, No. I., p. 152 A). A system of continuous casting for steel foundries is also briefly described.

Mechanical Handling in Foundry Practice. D. C. Paterson. (Institute of British Foundrymen: Foundry Trade Journal, 1942, vol. 68, Nov. 12, pp. 231–236; Nov. 19, pp. 255–260). The author reviews present foundry practice from the standpoint of the mechanical handling engineer. A foundry offers scope for almost every form of lifting and moving plant, and there is every opportunity for ingenuity of design. The handling of the raw materials, metals, coke and sand is dealt with; under sand handling the movement of mould boxes to the shake-out equipment and of the sand from there to the reconditioning plant and storage hoppers is described, with illustrations and diagrams of many types of equipment and layout.

PRODUCTION OF STEEL

(Continued from pp. 9 A–12 A)

Development of Western Iron and Steel Industry. J. R. Mahoney. (Steel, 1942, vol. 111, Sept. 21, pp. 79–84, 100–104). The author compares the geographical situation in relation to raw materials and markets of the existing and contemplated iron and steel plants in Utah with that of other steel-producing districts of the United States. It is planned to build an integrated coke-oven and iron and

steel plant at Geneva in Utah which will bring the total pig-iron production for this State up to 2,000,000 tons per annum and the open-hearth steel capacity up to 1,098,000 tons per annum. It is considered that the present demands and the post-war prospects provide ample justification for this increase in productive capacity.

Iron and Steel in Nazi Germany. (Engineer, 1942, vol. 174, Oct. 23, pp. 342–344). A review of the development of the iron and steel industry of Germany in relation to war economy is presented. Although opposed by most industrialists on sound technical and financial grounds, the Hermann Göring Works has grown from comparatively modest beginnings into a position unequalled by any other industrial trust in modern European history. There was a unique chance for Germany to reconsider her iron-ore policy after the conquest of France and the Low Countries in 1940, but no plan was made to exploit the minette ores of Luxembourg or the Lorraine ores. In June 1942 a new compulsory organisation was formed with large powers for directing the production and distribution of iron and steel; this huge vertical cartel tries to carry rationalisation still further than before. A gigantic scrap collection campaign has been carried through in July–September 1942 under the auspices of the Reich Minister for Economic Affairs. Owing to her territorial gains and economic agreements with Finland and Turkey, it is not likely that the production of high-grade steel will ever be made impossible in Germany through lack of alloying elements.

Modern Methods of Producing Plate Glass and a Comparison with Steel Production. H. Jebson-Marwedel. (Stahl und Eisen, 1942, vol. 62, Oct. 8, pp. 858–863). After describing two modern methods of manufacturing plate glass, the author presents and discusses data relative to the size, capacity, melting time, heat consumption and refractory brick consumption of glass furnaces and open-hearth steel furnaces.

Heating Open-Hearths with Coke-Oven Gas. E. Gnida. (Iron and Coal Trades Review, 1942, vol. 145, Nov. 13, pp. 1141–1142). An abridged English translation is presented of the author's report on the first campaign of a 50-ton open-hearth furnace fired with coke-oven gas (*see* Journ. I. and S.I., 1942, No. II., p. 207 A).

The Basic Open-Hearth Process To-day. Part III. Melting Practice. W. Geary. (Metallurgia, 1942, vol. 26, Oct., pp. 213–218). Continuation of a series of articles (*see* p. 10 A). The author points out that the idea that an open-hearth furnace can be worked at will as an oxidising or reducing apparatus is false; the true position is that oxidation can be subjected to a certain amount of control, but it cannot be stopped. It is not now generally considered that the oxygen content of the bath corresponds to equilibrium in the partition of oxides between metal and slag; the normal slag has an excess of FeO, forming as it were a " head " which supplies oxygen to the reaction zone assisted by the stirring action of the boil. Slag control by controlling the charge and the additions, deoxidation

practice and cleanliness, the production of rimming steel, control of grain size and the making of low-alloy steels in the basic open-hearth are dealt with in turn, and in conclusion brief reference is made to the Perrin process (*see* Journ. I. and S. I., 1940, No. II., p. 35 P).

The Manufacture of High-Quality Low-Cost Steel. P. J. McKimm. (Steel, 1942, vol. 111, Sept. 28, pp. 68–72; Oct. 5, pp. 130–132, 277–280). Conclusion of a series of articles (*see* Journ. I. and S.I., 1942, No. II., p. 207 A). The author discusses factors affecting the heterogeneity of steel ingots and methods of improving steel quality. When solidification begins and the rimming action is most vigorous, about 80% of the gas evolved consists of carbon monoxide. The proportion of hydrogen is small at first, but it increases as the rimming action subsides. The proportion of nitrogen decreases rapidly. Hydrogen and nitrogen migrate towards the ingot wall.

The distribution of sulphur and phosphorus in slab ingots of different thickness has been examined in ingots measuring 16 × 48, 20 × 48, 24 × 48, 32 × 48 and 17 × 17 in. A wide variation in analysis at the top of the ingots was noted, and ingots 24 in. thick were recommended for rolling in wide strip mills. With still heavier ingots the best results with regard to segregation, slab yield and uniform ultimate quality were secured with 32 × 48 in. ingots. When killed steel was teemed into moulds with a green wooden block placed on the mould stool, the effect was to close up the pipe at the top and to promote secondary pipe lower down in the ingot. Puddling the top of a rimming-steel ingot with green saplings had little effect, but with killed steel it was beneficial in reducing the amount of pipe. The use of green poles was most advantageous in the risers for steel castings, especially when casting mill-rolls. Tests with 3-in.-thick cast-iron caps and caps of sheet-bar crops on rimming-steel ingots showed that the latter improve the sulphur segregation. The effect of insulating an ingot mould by encasing it in foundry sand and covering the top with asbestos after teeming was examined; the steel had a ladle analysis of carbon 0·08%, manganese 0·32% and sulphur 0·028%, but in the ingot the carbon varied between 0·04% and 0·09% and the sulphur between 0·018% and 0·068%, which greatly exceeded the variation in an ingot of the same steel cast in an uninsulated mould. Inserting long sheet-metal strips 76 in. × 18 in. × 12 gauge in a mould before teeming did not improve the segregation or promote better quality.

A method of producing sound ingots is that of jarring or shaking the moulds while the ingot is being poured and until solidification commences. The technique developed at several works is that by which several car-loads of ingots can be jarred by raising and lowering them ½ in. 120 times per min., and it was found beneficial to increase the time for the downward movement from 0·05 sec. to 0·17 sec. It is claimed that jarred ingots have a thick skin, less

chemical segregation and a far greater yield than normally-poured ingots, but more conclusive evidence of this is awaited.

Distribution of Manganese and of Sulphur between Slag and Metal in the Open-Hearth Furnace. L. S. Darken and B. M. Larsen. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1481 : Metals Technology, 1942, vol. 9, Aug.). In this treatise, which is mainly mathematical, the authors show how to determine the distribution of manganese and sulphur between metal and slag in the basic open-hearth furnace over a wide range of slag composition. The distribution ratio at equilibrium depends on concentration factors that are directly determinable from the chemical analysis of the slag and metal. The following conclusions are drawn respecting the conservation of manganese and the removal of sulphur : (1) The retention of manganese in the steel is favoured by a high concentration in the slag of MnO relative to FeO ; (2) the optimum slag composition for the maximum retention of manganese in the steel is one corresponding to an effective lime/silica ratio of between 2·3 and 2·5 ; (3) a high ratio of sulphur in the slag to that in the metal is favoured by (*a*) a high concentration of free CaO and MnO in solution in the slag, (*b*) a low concentration of FeO in the slag, and (*c*) a low concentration of SiO_2 and P_2O_5 in the slag which will reduce to a minimum the number of large silicate and phosphate compound molecules present in the liquid slag ; (4) a small slag volume assists in the retention of manganese in the metal but is only consistent with good sulphur retention in the slag up to a certain point, in so far as it can be promoted by a low-silicon high-manganese charge ; if, however, still better sulphur elimination is required, or if the charge is high in silicon, more lime must be added, with a consequent increase in slag volume, which in turn causes a decrease in manganese recovery ; (5) in the metal, substantially all the sulphur can be regarded as being present as FeS, and less than 5% as MnS ; (6) lime present in the slag in excess of that required to form $2CaO.SiO_2$ is available for the compound $3CaO.SiO_2$; the latter dissociates much more than the former however ; (7) in slags with a lime/silica ratio of less than 2·0, both MnO and FeO replace $2CaO.SiO_2$ to some extent, MnO being somewhat more active in this respect ; and (8) calcium sulphate and calcium ferrite, which are continuously formed to some extent at the upper slag surface, appear to be dissociated to a much greater degree at the slag-metal interface ; thus, these act as oxygen carriers downward through the slag.

Continuation of the Investigations of the Acid Open-Hearth Process. Bo Kalling and N. Rudberg. (Jernkontorets Annaler, 1941, vol. 125, No. 7, pp. 283–325). (In Swedish). The authors report on further investigations of the acid open-hearth process in which the effects of working at a comparatively low temperature, and of the deoxidation and tapping conditions were studied. (*See* Journ. I. and S.I., 1937, No. II., p. 67 A, for a report on the earlier

investigations). The results indicated that the product [C] × [O] will be nearer to equilibrium the higher the temperature, and the oxygen content of the steel bath may be considerably increased when the temperature is so low that the reduction of silicon is retarded. Examination with the microscope revealed that there were not many inclusions in the steel bath before the deoxidation, at least in normally worked (not too cold) heats. This seems to be the case also after deoxidising high-carbon heats. In low-carbon heats, on the other hand, where the oxygen content is comparatively high, a precipitation of silicate inclusions seems to take place as soon as silicon is added. From a quality point of view it does not appear to matter whether the additions of silicon and manganese are made in the form of ferro-manganese, ferro-silicon or silico-manganese, nor in which order the addition of the two elements is made. A momentary precipitation of silica or silicates will of course take place when silicon or manganese is added and the concentration is raised locally over a certain limit, but such precipitations are immediately dissolved as soon as the homogeneity of the bath is restored. When the steel is tapped into the ladle and moulds, the stream is exposed to the influence of the air, which causes, among other things, a marked increase in the nitrogen content of the steel. It may appear strange that the oxygen content is not simultaneously increased; in high-carbon steel, however, it is the carbon which is primarily oxidised, whereas the silicon and manganese are protected from oxidation. Thus, the main product of oxidation during teeming is carbon monoxide, which escapes to atmosphere. If, on the other hand, the carbon content is low, other alloying elements will be oxidised first, and these will form oxides which remain in the steel; a considerable increase in the oxygen content of the steel will therefore occur during the tapping operation. The addition of lime to the slag in the bath had no detrimental effect on the refining process, the analysis of the steel or the number of inclusions.

An Evaluation of Factors Affecting Iron Oxide in Open-Hearth Liquid Steel. J. E. Gould and H. J. Hand. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1442: Metals Technology, 1942, vol. 9, Aug.). In order to evaluate the iron-oxide content of an open-hearth steel bath so that the most desirable level of oxidation can be obtained, and to secure precise information on which to base the final deoxidation, a new method, described in this paper, has been worked out at the National Tube Company's plant. Simultaneous slag and metal tests were made, and the separate and combined effects of a number of factors influencing the iron-oxide content were evaluated by statistical methods; these factors were the contents of carbon, manganese, (MnO), (FeO), (Fe_2O_3), the temperature and the R value for the slag. $R = \%CaO \div (\%SiO_2 + 0{\cdot}634\%P_2O_5)$. The results are given in tables and several series of curves. It was found that carbon is the predominating factor and the total iron in the slag is next in import-

ance; the temperature, basicity of the slag, and residual manganese are statistically important, but their actual effect is not very great. The factors examined were found to account for 90% of the variation in the iron-oxide content of the metal.

The Process for the Refining of Pig Iron in the Electric Steel Furnace. E. Berg. (Jernkontorets Annaler, 1941, vol. 125, No. 8, pp. 423–435). (In Swedish). The author describes three methods of producing high-quality steel in a Héroult basic electric furnace as practised at the Wikmanshytta in Sweden. These methods are: (1) Using a charge with about 70% of molten pig iron; (2) charging with alternate layers of cold pig (35% of charge) and steel scrap (20% of charge) with a weighed amount of dry slig (a concentrate containing 68% of iron) and some limestone; above this more cold pig (35% of the charge) in granulated form is charged; and (3) when no granulated iron is available, charging with 60% of the cold pig first, melting this down and superheating to about 1350° C. and tapping off into a ladle; the furnace is then recharged with the remaining cold pig, the scrap and slig, and the iron in the ladle is later poured back into the furnace. In each method the total charge is about 10 tons, of which 70% is pig iron. The charge is worked with two slags, the first, an oxidising slag, being tapped off, and a second reducing slag being worked up before final tapping. Tables of typical charging data are presented, together with curves showing the carbon drop as the refining proceeds.

The Manufacture of Tool Steel in the United States. H. Nathorst. (Jernkontorets Annaler, 1941, vol. 125, No. 12, pp. 653–694). (In Swedish). In the winter of 1938 the author visited some of the steelworks in the United States which make special steels, tool steels in particular. In this paper he reviews the methods of production, including details of charges, temperature measurement, tapping and ingot moulds, and describes the forms of heat treatment and methods of testing.

Control Method for Electric Arc Furnaces. T. B. Montgomery. (Steel, 1942, vol. 111, Sept. 14, pp. 145–150, 174). The author discusses the theory of current fluctuations in the operation of an electric arc furnace. In melting down a fresh charge of scrap metal the current must traverse a long path of loose heterogeneous material between the electrodes, as well as the vaporous arc stream; under such conditions the resistance will fluctuate wildly. In some cases current surges occur as rapidly as every six cycles on a 60-cycle system. No mechanical system can follow such violent irregularities, so that what is required is a control system with a time rate of response which follows average conditions. A control system to meet these requirements is described.

Increasing Steel Production. J. Winning. (Mechanical World and Engineering Record, 1942, vol. 112, Oct. 30, p. 407). A brief review of some methods of increasing the production of electric steel furnaces is presented. Reference is made to a method of teeming

ingots which is being developed at a new steelworks in Brazil. It is called "impact casting"; the principle of the method is to supercool the steel by allowing it to pass between two large rollers placed between the ladle and the head of the ingot mould.

What is the Effective Time and the Idle Time of Your Travelling Crane? W. Abhöh. (Stahl und Eisen, 1942, vol. 62, Oct. 8, pp. 867–868). The author describes how to make a study of the working and idle times of steelworks cranes used for handling ingots.

Steel Mill Lighting in Wartime. J. P. Ditchman. (Iron and Steel Engineer, 1942, vol. 19, Sept., pp. 128–133). The author makes recommendations as to the type, power, number and position of electric lamps in steelworks buildings and for the illumination of boundary fences.

FORGING, STAMPING AND DRAWING

(Continued from p. 13 A)

Drop Hammer Forming of Aircraft Parts. C. H. Miller and R. B. Stubbs. (Iron Age, 1942, vol. 150, Aug. 27, pp. 59–62). The authors describe and illustrate some of the drop-hammer forging machines used by the Bell Aircraft Corporation, Buffalo, for manufacturing aircraft parts, in particular instrument panels and door-frames.

Building Hammers at Chambersburg. A. F. Macconochie. (Steel, 1942, vol. 111, Sept. 11, pp. 112–116, 182, 183). The author discusses points in the design and construction of heavy steam-hammers as practised by the Chambersburg Engineering Co. in the United States. Reasons for and against designing a hammer in which the head and the anvil move towards each other are given. The methods of aligning and fixing of the piston rod in the head are described.

Backing-Up Rolls. J. A. Succop. (Iron and Steel Engineer, 1942, vol. 19, Sept., pp. 42–47). The author describes how backing-up rolls for rolling strip are made. These rolls are frequently of composite construction, consisting of a sleeve shrunk on to an arbor. The arbor may be made by turning down a worn solid roll or from a new forging. To make the sleeve, an ingot of electric-furnace or acid open-hearth steel is rolled into a billet; the required weight is cut off, upset-forged, hot-punched and forged on a mandrel; it is given careful heat treatment both before and after rough-turning; the sleeve is then shrunk on the arbor, and final turning is completed on the composite roll. It is usual to express the life of a roll in terms of the tonnage rolled, but this does not take into account the stand in which the roll is used, for the stands in a mill produce different degrees of reduction; it is therefore

suggested that the unit for comparing the lives of rolls should be the roll circumference in feet per ton of steel produced.

Bolts—Material, Heat Treatment and Physical Properties. A. S. Jameson. (Iron Age, 1942, vol. 149, May 7, pp. 57–60; May 14, pp. 52–57, 129). The author discusses the properties of low-carbon, medium-carbon and alloy steel bolt material. The limitation placed on using wire-drawing as a means of increasing bolt strength is that sufficient plasticity must be retained in the rod so that it can be used in the cold-heading operation, with the result that, in practice, only one draft can be employed. After cold-heading, low-carbon steel bolts are given a process anneal to return some degree of plasticity to the cold-worked head; this anneal also reduces the tensile strength of the threaded portion to some extent. To maintain a good die life when heading medium-carbon (0·30–0·45%) cold-drawn steel wire, the wire is treated before drawing by annealing at above or below the critical range; the former produces a pearlitic structure and the latter a spheroidised structure; the spheroidised structure has superior heading properties. The analyses and strength properties of bolts of a wide variety of steels are given in numerous tables and diagrams.

The Origin of Wire Drawing Dies. P. Grodzinski. (Wire and Wire Products, 1942, vol. 17, Aug., pp. 401–402). The author refers to an earlier paper by K. B. Lewis on the history of wire drawing (*see* Journ. I. and S.I., 1942, No. II., p. 13 A) and makes his own contribution on this subject. In the present author's opinion the drilling of stones to make drawing dies preceded the use of drilled stones for watch bearings.

ROLLING-MILL PRACTICE

(Continued from pp. 13 A–15 A)

Motor Applications and Power Requirements for Strip Processing Lines. H. W. Poole. (Iron and Steel Engineer, 1942, vol. 19, Sept., pp. 33–40). The author presents and discusses data on the current input to motors driving auxiliary strip-rolling machinery such as side trimmers, levellers, leveller-shears, uncoilers with and without tension, pinch rolls and tension reels.

Engineering for Increased Production in the Steel Industry. R. H. Wright. (Iron and Steel Engineer, 1942, vol. 19, Sept., pp. 123–127). Some examples are given of alterations which have been made to rolling-mill motors and other rolling-mill equipment with the object of increasing output.

Systematic Inspection and Maintenance of Steel Plant Electrical Equipment. W. A. Perry. (Iron and Steel Engineer, 1942, vol. 19, Sept., pp. 113–120). The author gives a description of the system of

regular inspection and maintenance work which has been developed by the electrical department of the Inland Steel Co., East Chicago. This system has resulted in much lower repair costs and fewer interruptions to the rolling-mill production.

Maintenance of Electrical Equipment in Steel Plants. M. J. Wohlgemuth. (Steel, 1942, vol. 111, Sept. 14, pp. 153–156, 181). Some practical recommendations on the cleaning, lubrication and general maintenance of electrical equipment in steel plants, especially rolling mills, are made.

Roll Pressures in Rolling Steel Strip. J. D. Keller. (Steel, 1942, vol. 111, Sept. 14, pp. 160–166, 198). The author explains W. Trinks' method of calculating roll pressures in the cold-rolling of strip (*see* Journ. I. and S.I., 1937, No. II., p. 225 A). The proper use of the method is illustrated by working out examples from practice and comparing the calculated pressures with the pressures actually measured.

Roll More Tons. III. Tee Calibrations. A. Lendl. (Iron and Steel, 1942, vol. 16, Oct., pp. 5–9, 14). In the third of this series of articles (*see* p. 14 A) the author shows that the lateral spread of the material can also be calculated in the case of calibrations of T sections, thus providing the roll-pass designer with the means of laying-out the grooves of his calibrations with the greatest accuracy.

Novel Cold Reducing Mill. W. A. Phair. (Iron Age, 1942, vol. 149, May 7, pp. 76–77). The author describes the "Simons" mill for the cold-reduction of steel strip. This mill consists of a 4-high stand with steel working rolls 1½ in. in dia. and cast-iron backing rolls 8 in. in dia. The novel feature of the mill is that the upper and lower pair of rolls are given a reciprocating motion of 3 in. in opposite directions and transverse to the rolling direction. The backing rolls are driven by a 35-h.p. motor, and the work-rolls by the friction from the former. The strip is pulled through the rolls at 500–600 ft. per min.—a speed which is greater than the surface speed of the working rolls—the strip is thus drawn as well as rolled. The small diameter of the working rolls makes the entrance angle for the strip a large one, and the strip is not hardened as much as it would be by rolls of greater diameter. It is therefore possible to make larger reductions in each pass and a very large total reduction in the strip thickness without intermediate annealing.

PYROMETRY

The Calibration of the Platinum/13%-Rhodium–Platinum Thermocouple over the Liquid Steel Temperature Range. C. R. Barber. (Iron and Steel Institute, 1943, this Journal, Section I.). The quick-immersion technique for determining the temperature of liquid steel is now so well established that an accurate calibration

of the thermocouples is clearly desirable. A full description of the apparatus and technique for this calibration has been published elsewhere (*see* next abstract). In this paper the author describes how the e.m.f.'s of eight platinum/13%-rhodium–platinum thermocouples were measured at the melting points of gold, palladium and platinum by the wire method. On the basis of these determinations and the existing e.m.f./temperature relation up to 1550° C., a reference table for the platinum/13%-rhodium–platinum thermocouple covering the range 1400° to 1770° C. was computed. It is estimated that the accuracy of the calibration in terms of the International Temperature Scale is ± 3° C. up to 1600° C. and ± 5° C. beyond this temperature.

The Technique of Calibrating Platinum Thermocouples for Use in Liquid Steel. (London, 1942: H. M. Stationery Office). A description is given of the technique employed at the National Physical Laboratory for checking and calibrating the platinum/platinum–rhodium thermocouples in the "Schofield quick-immersion" method of measuring the temperature of liquid steel (*see* Journ. I. and S.I., 1942, No. I., p. 222 P).

HEAT TREATMENT

(Continued from pp. 15 A–17 A)

Accurate Dew Point Indication for Atmospheres of Heat-Treating Furnaces. P. R. Kalischer. (Steel, 1942, vol. 111, Sept. 14, pp. 110–111). The author describes an electrical instrument through which a continuous stream of hydrogen for heat-treatment furnaces can be passed. Its purpose is to give accurate indications of the amounts of moisture and oxygen which may be present.

Heat-Treatment Response in Certain Non-Alloy Steels. B. Thomas. (Metallurgia, 1942, vol. 26, Oct., pp. 199–201). The author discusses how the properties of heat-treated high-carbon steels may vary when the other elements, particularly manganese, fluctuate. The results of tests on five types of steel containing 0·50–0·53% of carbon with 0·51%, 0·60%, 0·72%, 0·80% and 0·92% of manganese respectively, showed that, while it is usual to expect, and possible to obtain, increased tensile strengths with rising manganese contents, no appreciable difference was observed with these steels when in the normalised state. On quenching, some difference was apparent, and this was more marked after tempering. Of course sulphur has a greater affinity for manganese than for iron, and some manganese is thus taken up which otherwise would be of assistance in widening the hysteresis on quenching. The author suggests the following method of arriving at a scale of hardening values for a series of steels: Multiply the sulphur content by 10;

deduct the product from the manganese content, and add one-third of this difference to the carbon content. Applying this method to the five steels investigated it was found that the increase in tensile strength with increasing manganese was fairly accurately represented by the rise in these hardening values.

The Hardening and Tempering of Steel Direct from the Heat of Rolling. R. Schäfer and W. Drechsler. (Stahl und Eisen, 1942, vol. 62, Sept. 24, pp. 809–813). The authors refer to their earlier paper on the hardening of low-alloy steels by cooling slowly to the A_1 point, and then rapidly quenching (*see* Journ. I. and S.I., 1942, No. II., p. 214 A), and report on some tests undertaken to ascertain whether it was economically possible to harden rolled steels in this way direct from the heat of rolling. Unalloyed and alloyed steel billets 160 × 125 mm. were rolled down to 60-mm.-dia. round bars which were divided into three lots on leaving the last pass. One lot was immediately quenched in water; the second lot was put in a furnace for 30 min. to soak at 730–760° C. and then quenched in water; the third lot was allowed to cool in air and was then hardened in the ordinary manner by heating and quenching. Hardness, tensile and impact tests were made on specimens, and the results are compared in tables; micrographs of the structure are also shown. It was found that it was quite feasible to utilise the rolling heat for carrying out the above form of heat treatment. The temperature at the first pass must be selected to suit the composition of the steel and the number of passes. For vanadium steels the temperature at the last pass should be in the 880–730° C. range; for vanadium-free steels it should be 860–760° C.

Special Phenomena in Connection with the Scaling of Heat-Resistant Steels and Alloys. G. Bandel. (Iron and Steel Institute, Translation Series, 1942, No. 116). An English translation is presented of the author's paper which appeared in Archiv für das Eisenhüttenwesen, 1941, vol. 15, Dec., pp. 271–283. In this paper the properties of two types of scale and the conditions promoting their formation on steel are discussed. (*See* Journ. I. and S.I., 1942, No. II., p. 17 A).

WELDING AND CUTTING

(Continued from pp. 17 A–21 A)

Building-Up and Hardfacing in Mill Maintenance. S. D. Baumer. (Steel, 1942, vol. 111, Sept. 14, pp. 170–172; Sept 21, pp. 70–72). Some examples of the repair and maintenance of rolling-mill machinery and equipment by hard-facing with the oxy-acetylene torch or by electric welding are described and illustrated.

Proposed Specifications for Stainless Steel Arc-Welding Electrodes for Welding Steels of High Hardenability. (Welding Journal, 1942,

vol. 21, Aug., pp. 513–514). A proposed specification prepared by the Filler Metal Specifications Committee of the American Welding Society for three types of stainless steel electrodes for welding low-alloy steels is published. Two of the types are 18/8 steels, one with 2–5% of manganese and the other 1–4% of molybdenum; the third is a 24/19 chromium-nickel steel.

The Effect of Sodium and Potassium Silicates on the Properties of Weld Metal. G. Haim and D. McAllister. (Transactions of the Institute of Welding, 1942, vol. 5, July, pp. 133–135). The authors report on their investigation of the effects of sodium and potassium silicates in the flux coatings on welding electrodes on the properties of the metal deposited. The tests were carried out with five different types of silicate solutions and their mixtures using titanium-base coatings. Sodium silicate as a binder in these coatings caused a higher arc voltage and more splutter then potassium silicate. The metal deposited with sodium silicate in the coating has a lower tensile strength and greater elongation than when potassium silicate is used. The carbon and silicon contents of the weld metal are not appreciably influenced by the binder. A relationship between the type and grade of binder and the manganese recovery could not be established owing to the wide variations in the manganese content of the weld metal.

The Oxy-Acetylene Treatment of Metals in the Repair Department of the Swiss State Railways. R. Weyermann. (Autogene Metallbearbeitung, 1942, vol. 35, Mar. 15, pp. 77–84). The author gives an account, with numerous illustrated examples, of repair work carried out with the oxy-acetylene torch in the repair shops of the Swiss State Railways.

The Effect of Notches and Internal Stresses on the Fatigue Strength of Welded Joints. A. Thum and A. Erker. (Autogene Metallbearbeitung, 1942, vol. 35, Feb. 15, pp. 49–56). The authors describe visible and invisible notches which sometimes occur on the surface of welds at the junction of the weld metal and the parent metal, often due to using too high a current for welding. They also describe an investigation of the effect of these notches and of internal stresses on the fatigue strength of the joint. As a rule too much apprehension exists about the effect of internal stresses. In mild steels the reduction in fatigue strength which they cause is about 10–15%. In high-tensile steels it is more than this, and for a weld subjected also to external stress the reduction may exceed 30%. Internal stresses are dangerous only when it is necessary to weld while the structure is subjected to external stress. This difficulty may be overcome by designing the structure with some elasticity. Multiple tube joints with several welds in one place should be avoided, or a stress concentration may be prevented at such places by applying heat at another spot so as to create compression stresses at the joint while welding is in progress.

The Arc Welding of Alloy Steels. C. P. Keogh. (Australian Institute of Metals, Australasian Engineer, 1942, vol. 42, Aug. 7,

pp. 15–16, 45–47). The author discusses the theory and practice of the electric welding of alloy steels with special reference to the effect of the elements carbon, nitrogen, oxygen, manganese, sulphur, silicon, phosphorus, nickel and chromium on the heat-affected zone and on the weld metal. The conditions under which previous or subsequent heat treatment are required are also dealt with.

Welding Chromium Steels. Part I. Low-Alloy High-Strength Chromium Steels (Cr $\leq$ 1%). W. Spraragen and H. H. Chiswik. (Welding Journal, 1942, vol. 21, Aug., pp. 353-S–384-S). The authors present a review of the literature from July 1937 to January 1941 on the welding of low-alloy steels containing up to 1% of chromium.

Welding Stainless Steel Sheets. A. J. T. Eyles. (Sheet Metal Industries, 1942, vol. 16, Oct., pp. 1553–1556, 1558). The author describes the techniques for oxy-acetylene and electric welding of stainless steel sheet.

Spirally Brazed Tubing. W. A. Phair. (Iron Age, 1942, vol. 150, Sept. 17, pp. 55–57). The author describes a method of making steel tubing of small diameter which has been developed by the Aga Metal Tube Co. of Elizabeth, N.J. The raw material is cold-rolled steel strip from 0·008 to 0·042 in. thick. This is first fed through a broaching machine in which both edges are bevelled. The reel of bevelled strip is then transferred to a spiralling unit which winds it into a helical tube. This tubing is fed through a high-frequency induction brazing furnace in which the spiral seam is brazed in a protective atmosphere. On leaving the furnace the tubing is red hot, and it passes next into a cooling chamber, within which there is a tension device the object of which is to apply pressure on the brazed seam while the joint is still plastic. The final operations are those of cutting off in the required length and testing.

Abrasive Cut-Off Wheels—Where and How to Use Them. F. A. Upper. (Iron Age, 1942, vol. 150, Sept. 10, pp. 48–51; Sept. 17, pp. 69–72). The author discusses the cutting of metals with abrasive discs. The advantages of this method include the short time required for the cut, the clean surface left, accuracy attainable and rapid cooling as compared with oxy-acetylene cutting. Tables of data on wheel speeds and sizes, cutting times and wheel life when wet- and dry-cutting tubes, angles and bars of non-ferrous and ferrous metals are given. The merits of dry and wet cutting are compared.

PROPERTIES AND TESTS

(Continued from pp. 29 A–33 A)

Tensile Tests with the Specimen Surrounded by a Liquid. G. Malmberg. (Jernkontorets Annaler, 1941, vol. 125, No. 12, pp. 695–697). (In Swedish). The author submits a brief report on the

results of tensile tests on specimens of a 0·60% carbon steel in which the specimens were held in a sleeve which was kept filled with a liquid. The liquids used were river water, distilled water, 1% hydrochloric acid, 10% sodium citrate and 5% soda solution. In some tests the specimen was held for 14 hr. with a load just above the elastic limit. None of the liquids had any appreciable effect on the elastic limit or the tensile strength, but the acid solutions slightly reduced the elongation and reduction-of-area values.

The Effect of After-Treatment on the Properties of Steel Wire. W. Püngel. (Stahl und Eisen, 1942, vol. 62, Oct. 8, pp. 853–858; Oct. 15, pp. 876–879). The author reviews experience gained by the Vereinigte Stahlwerke A.-G., concerning the effects of heat treatment and deformation on the properties of steel wire. Tempering at between 250° and 350° C. increased the elastic limit and tensile strength of drawn steel wire, whilst tempering at higher temperatures had the opposite effect; the reduction in tensile strength was greater the greater the reduction of area on drawing and the longer the tempering time. The reduction of area in the tensile test decreased with decreasing tempering temperature below 250° C.; at above 250° C. it increased with increasing tempering temperature for small reductions on drawing, but for large reductions it decreased; for medium reductions on drawing the reduction of area was not affected by the tempering temperature. The effects of hand- and machine-straightening and tempering at different temperatures on the tensile and fatigue properties of drawn steel wire are given in several diagrams. Methods of measuring residual stresses in drawn wire are discussed, and results of tests on the effects of tempering temperature and time on the residual stresses in wire drawn with different degrees of reduction are presented. The greater part of these stresses can be relieved by tempering at 250–350° C. for a very short time (20 sec. at 350° C. is usually sufficient). The properties of hot-dipped galvanised cold-drawn wire depend not only on the tempering time and temperature, but still more on the carbon content and amount of reduction; high carbon and a heavy reduction are favourable factors. The cleaning and pickling have a pronounced effect on the deformation properties of the zinc coating; the more thorough this is the less is the tendency of the zinc to harden.

Recent Development of Steel St 52 for Steel Structures. E. H. Schulz and D. W. Bischof. (Iron and Steel Institute, 1941, Translation Series, No. 57). This is an English translation of a paper which appeared in Zeitschrift des Vereins Deutscher Ingenieur, 1941, vol. 84, May 6, pp. 229–235, and it is reproduced by permission of the Ministry of Aircraft Production. Structural steel St 52 was introduced in Germany in 1928 for the construction of riveted bridges. With the increased application of welding it was found necessary in 1937 to restrict the alloy constituents to improve the weldability. By heat treatment and modifications in the steel-production process the steelmakers improved the weldability. A

bend test on longitudinal fillet welds is described in detail, and the results obtained with specimens of this steel are related to the grain size and type of heat treatment.

Converter Cast Steel Will Meet Requirements. C. E. Sims and F. B. Dahle. (American Society for Testing Materials: Foundry, vol. 70, 1942, Sept., pp. 88–89, 151–157; Steel, 1942, vol. 111, Sept. 11, pp. 125–128, 187–191). The authors report on an investigation carried out at the Battelle Memorial Institute in which a comparison was made of the mechanical properties of specimens of cast steel of similar analyses made by six different processes, viz.: (1) Acid open-hearth; (2) basic open-hearth; (3) acid electric; (4) basic electric; (5) the triplex process, *i.e.*, cupola/Bessemer-converter/electric-furnace; and (6) side-blown converter. The steels contained small amounts of copper, chromium and nickel, and carbon in the 0·20–0·35% range, and represented current standard practice at the works which supplied the specimens. It was desired to ascertain whether side-blown converter cast steel differed materially in mechanical properties from cast steels made by the other processes. Side-blown converter steels are said to have poor impact strength properties at low temperatures, and particular attention was paid to this by making Charpy impact tests at down to − 80° F. These steels were found to have as a group the best low-temperature impact properties. On the whole, no evidence was found to favour any particular process, except that better control of the phosphorus could be achieved in the basic open-hearth. With proper deoxidation, all the processes will produce steel of the quality demanded for war purposes.

Investigations on a New Shape of Specimen for Impact Tests. A. Wahlsteen. (Jernkontorets Annaler, 1941, vol. 125, No. 6, pp. 217–247). (In Swedish). The author reports on a comprehensive investigation of the advantages of using a new type of specimen for impact testing. The results obtained in several series of test are compared with those obtained using standard Charpy specimens of the same steel. The new type of specimen is the same size as the Charpy specimen, namely, 55 × 10 × 10 mm., but instead of having an open notch it has a " closed " one—in other words, a round hole. Nine varieties of the new type were tested; these differed in the size of hole and distance from the surface. The nine specimens were numbered in a manner indicating the size and position of the hole, *e.g.*, specimen 541 had a 4-mm.-dia. hole the sides of which were 5 mm. from the impact side and 1 mm. from the other side of the specimen. A variety of steels with carbon in the 0·12–1·02% range, heat-treated in various ways, were tested. With regard to the scatter of the test results several of the holed specimens (especially Nos. 451 and 352) were superior to the Charpy specimens. With steels of low impact strength the holed specimen gives a better discrimination between brittle and ductile steels than the Charpy specimen. The influence of machining defects in the preparation of

the specimens became more marked as the distance of the hole from the impact side decreased. The general conclusion was that under many conditions of testing the holed specimen is superior to the standard Charpy specimen.

The Tensile-Impact Test and Its Application. K. G. Olsson. (Jernkontorets Annaler, 1941, vol. 125, No. 6, pp. 249–274). (In Swedish). The author describes the apparatus and procedure for making tensile-impact tests, and discusses the relationships between the results of these tests and those of static tensile and ordinary impact tests. The results of many tests, including some with the holed specimens described in the preceding abstract, are compared. The conclusion is drawn that tensile-impact tests on plain specimens (*i.e.*, with no notch or hole) give a poor indication of whether the steel is brittle or tough. A suitable form of notched specimen gives a good indication, and is also superior to the holed specimen 532 (*see* preceding abstract for meaning of numbers) with which the same values were obtained in other respects.

Tessellated Stresses. F. László. (Iron and Steel Institute, 1943, this Journal, Section I.). Anisotropy of the single crystals of most materials and the differences between the bulk physical properties of the components of compound solids readily cause internal self-compensated stress systems to develop round such centres as crystals or components of the compound structure, respectively. These self-compensated stress systems are called "tessellated stresses."

It is shown how to determine the order of magnitude of stresses due to crystal anisotropy. Those caused by differences in bulk properties are carefully investigated by the statistical application of the theory of elasticity.

A discussion is given of their influence on iron and steel, and some problems connected with other solids are mentioned.

Details of a New System of Crack Detection. (Sheet Metal Industries, 1942, vol. 16, Oct., pp. 1557–1558). A brief description of the "Glo-Crack" method of detecting cracks in metals is given (*see* Journ. I. and S.I., 1942, No. II., p. 217 A).

The Relation between Grain Strength and Boundary Strength in Minerals and Metals. P. J. Holmquist. (Jernkontorets Annaler, 1941, vol. 125, No. 6, pp. 190–206). (In Swedish). The author investigated the causes of the fracture of steel rope clamps, and discusses and compares the type of fracture with that of minerals and rocks. The clamps were made of 7-mm.-dia. rod in the form of a figure 8, with one loop elongated to a narrow neck, into which the rope is jammed. It was found that the core structure consisted of tightly packed ferrite grains of about 0·02 mm., with pearlite of somewhat smaller size in the grain boundaries; this structure is typical of that occurring when the material is heterogeneous at the temperature at which it is drawn into rod; from this it was concluded that dynamic segregation had occurred at a temperature

below 950° C., and that it is the orientation, and not the grain shape, which is characteristic of the disturbance which had taken place in the material. The plate structure is remarkably similar to the well-known granular structure observed in highly metamorphous schists.

Hardenability of Steel. A. E. Focke. (Iron Age, 1942, vol. 150, Aug. 20, pp. 37–40; Aug. 27, pp. 43–51; Sept. 3, pp. 56–59). The author reviews methods of determining the hardenability of steel, and presents and correlates data obtained by several investigators. The Jominy end-quench test is described, and an example is given of how the data obtained in this and other tests can be used to compare the properties of the S.A.E. steels 3140 and 1045 so as to determine whether the latter can be substituted for the former for making gears.

A Recording Dilatometer for Metal Specimens. L. R. Stanton. (Iron and Steel Institute, 1942, this Journal, Section I.). A dilatometer is described which produces a permanent record of the length changes of a metal specimen, with an accuracy of 0·001 mm. The range over which measurements can be made extends to about 0·2 mm., the sensitivity being adjusted to suit any particular requirement. The measuring principle involves the tuning of an inductance about its resonant point by means of a small condenser actuated by the dilatometer, and particular care is taken to ensure stability of the apparatus over long periods.

Precision in Creep Testing. J. A. Fellows, E. Cook and H. S. Avery. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1443: Metals Technology, 1942, vol. 9, Aug.). The authors give an account of the apparatus and technique developed by the American Brake Shoe and Foundry Co., for the creep testing of chromium-nickel heat-resisting steels. The laboratory is designed to permit 1000-hr. tests at temperatures in the 1200–2200° F. range, with a choice of applied stress extending from 50 to 50,000 lb. per sq. in. in increments of 50 lb. per sq. in. Specimens 16 in. long with a 4-in. gauge length are used, and the elongation measurements are made by sighting a telescope with crossed hair lines on reference marks cut in platinum-rhodium extensometers spot-welded to each side of the gauge length. Exceedingly accurate measurements can be made, because one drum division of the micrometer eyepiece is equivalent to 0·00000978 in. per inch for a 4-in. gauge length. Brief reference is made to the possibility of developing short-time creep tests by determinations of the time to failure at various loads and temperatures. Some particulars are given of an instrument for measuring the magnetic permeability of specimens in order to study the influence of ferrite on the properties of heat-resisting alloys. A bibliography with 83 references to the literature on creep-testing is appended.

Niobium as an Alloying Element in Heat-Resisting Steels. D. W. Rudorff. (Metallurgia, 1942, vol. 26, Oct., pp. 193–196, 224). An abridged English version of a recent paper by F. Wever and W. Peter

is presented. This dealt with the precipitation hardening and creep strength of iron-columbium alloys and of steels alloyed with columbium. (*See* Journ. I. and S.I., 1942, No. II., p. 72 A).

Rust-, Acid- and Heat-Resisting Steels. W. H. Hatfield. (Institute of Chemistry, May, 1942). The author begins by indicating how the war emergency has affected the special-steel situation, and presents lists of purposes for which rust-, acid- and heat-resisting steels are considered essential and not essential in war-time. The properties and microstructures of these steels are then briefly discussed. The heat-resisting steels are divided into the following groups: (1) Silicon-chromium steels; (2) 12–30% chromium steels; (3) austenitic chromium-nickel steels; and (4) higher nickel-chromium alloys containing 60% or more of nickel. In producing cutlery of stainless steel it was found that spoons and forks could not be economically produced in 18/8 stainless steel, owing to the number of operations, but that 12%-chromium 12%-nickel steel could be forged and pressed to the required shapes without any intermediate softening treatment. The addition of molybdenum to 18/8 stainless steel greatly increases its resistance to organic acid. The addition of titanium or columbium prevents the intercrystalline weakness which occurs if 18/8 steel has been cooled down from a dull red heat and then subjected to the attack of certain critical corroding media. Extensive tables of loss-in-weight data of several specifications of corrosion-resisting steel in nitric, sulphuric, hydrochloric, phosphoric and acetic acids at 20°, 40°, 60°, 80° C. and boiling point are presented. The "time-yield" method of assessing creep characteristics is explained; the time-yield stress is that approximately equivalent to a rate of creep of one-millionth of an inch per inch per hour. One of the latest heat-resisting steels can be stressed at up to 6·5 tons per sq. in. at 700° C. without the above creep rate being exceeded. Some notes on the hot- and cold-working, welding, brazing and machining of stainless steels are appended.

Alloy Steel Castings, Their Properties and Application. H. Juretzek. (Iron and Steel Institute, Translation Series, 1942, No. 114). An English translation is presented of a recent paper in which the author reviews the properties of alloy-steel castings for aircraft, motor transport, boilers, turbines and chemical plant. (*See* Journ. I. and S.I., 1942, No. II., p. 220 A).

Conserving the Alloying Elements of Light Armor Steels. A. F. Macconochie. (Steel, 1942, vol. 111, Oct. 5, pp. 172–180). The author gives a short account of the research programme of the Ferrous Metallurgical Advisory Board on the selection of steels of light armour with a view to using the least possible amount of alloying elements. Some developments in cast armour are noted. Information is also given on the occurrence and working-up of nickel, chrome, molybdenum and vanadium ores in North America.

Physical Properties of NE Carburizing Steels. A. S. Jameson (Iron Age, 1942, vol. 150. Sept. 17, pp. 58–64). The author com-

pares the properties of ten case-hardening National Emergency steels with those of pre-war standard alloy case-hardening steels. The origin and purpose of the National Emergency steels have been dealt with previously (*see* pp. 31 A and 32 A).

Cold-Rolled Stainless Steels in Aircraft. R. Franks and W. O. Binder. (Mechanical Engineering, 1942, vol. 64, Aug., pp. 589–598). The authors discuss the properties of cold-rolled stainless steel and the suitability of this material for making light high-strength structures. If the composition and the degree of cold-reduction are properly controlled, these steels have predictable stress-strain characteristics and can readily be fabricated into light and strong structures. When a tensile strength not much more than 150,000 lb. per sq. in. is required, the 18/8 quality is satisfactory, but for higher strengths such as 175,000 to 200,000 lb. per sq. in. the 17%-chromium 7%-nickel quality is to be preferred because of its higher ductility. High strength with somewhat greater ductility than that of the 17/7 steel is obtained with cold-rolled 17%-chromium 5%-manganese 4%-nickel steel. The compressive yield strength of 18/8 steel in the direction of rolling is not so high as the tensile yield strength. The compressive yield strengths of the 17/7 and the 17/5/4 steels are higher than that of 18/8, and more nearly approach their tensile yield strengths. The compressive yield strength of each steel is higher than the tensile yield strength in the direction transverse to rolling. The compressive yield strengths, especially in the direction of rolling, are greatly improved by heat treatment at 200–300° C.; usually 24 hr. treatment is sufficient. After this treatment the compressive and tensile yield strengths of the 17/5/4 steel are approximately equal.

METALLOGRAPHY AND CONSTITUTION

The Use of X-Rays in the Foundry. W. Montgomery. (Institute of British Foundrymen: Foundry Trade Journal, 1942, vol. 68, Oct. 22, pp. 159–170). The author explains in non-technical language the theory of X-ray generation and the application of X-rays to detect faults in castings; he then devotes the major portion of the paper to the interpretation of radiographs. Several radiographs are reproduced of castings, in some of which faults were purposely introduced, and these are compared with radiographs of similar sound castings. The factors studied in these examples included the degree of fusion obtained between a chaplet and an iron casting, the detection of shrinkage cavities, discovering the cause of bubbles in enamel and glass linings on the inside of cast-iron pipe bends, straights and T-pieces. Double-exposure technique is described and the method of calculating the position of a defect from the data obtained by this technique is explained.

Non-Destructive Testing for Autogenous Welding and Hardening. W. Kolb. (Autogene Metallbearbeitung, 1941, vol. 34, July 15, pp. 225–233). The author reviews the application of X-ray and magnetic-powder methods of examining welded and hardened steel parts, pointing out their limitations. A method of obtaining contact prints of a surface which has been examined by the magnetic-powder technique is described. A white, fine-grained absorbent paper is carefully moistened on one side and pressed with the fingers over the metal surface with the drier side down. If the paper has been carefully prepared it will make contact with all the hollows and ridges in the metal surface, such as those on a bead of weld metal, and the accumulations of powder will leave fine black lines on the paper.

Railway Engineering and Radiography. E. D. Knights. (Railway Gazette, 1942, vol. 77, Oct. 9, pp. 348–350). The author gives some examples of the X-ray technique employed by the London, Midland and Scottish Railway Co. for examining metals. The set-up of the apparatus and interpretation of radiographs of a weld in a steel pressure vessel, a butt-welded steel plate, fillet welds, a cast steel spoke, a cast steel motor housing and a zinc alloy die casting are explained.

Micro and Macro Structures of Gray Iron and Meehanite. C. R. Austin and M. M. Lipnick. (Iron Age, 1942, vol. 149, May 7, pp. 72–74; May 14, pp. 59–61, 129, 130). The authors describe the technique for grinding and polishing specimens of grey iron and Meehanite, and presents and compares macrographs and micrographs of these metals. In photographing, a backed plate, in which halation is largely eliminated, accurately reproduces the visual appearance of a properly polished specimen, and, if a suitable paper is used, the detail is transferred to the print. The effects of different developing solutions are also pointed out. In the second part of the paper a study of graphite flakes is made using the technique previously described. The difference between primary and secondary graphite flakes is clearly revealed, and it is stated that high tensile strength is associated with the absence of secondary graphite in cast iron.

Diffusion between Metals in the Solid State. F. Neumeyer. (Teknisk Tidskrift, 1942, vol. 71, June 28, pp. 277–284; July 5, pp. 285–288). (In Swedish). The author presents a review of past and present theories on the diffusion of metals in each other in the solid state.

Diffusion in Metal Accompanied by Phase Change. L. S. Darken. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1460: Metals Technology, 1942, vol. 9, Aug.). In this study of the diffusion of an element into a metal or alloy and its relation to scale formation in the case of steel, the author's objects are: (1) To demonstrate the conditions necessary for the existence of a sharp boundary between the diffusion zone, or subscale, and the base metal; (2) to describe a simple method of calculating the

composition and thickness of the subscale; and (3) to show how this method can be extended to cover complex cases. The paper is mainly of a mathematical nature, and the author explains how to determine the rate of growth and composition of an oxide subscale on an alloy from the diffusion constants, phase relations and boundary conditions. Large apparent deviations from Fick's law may be expected in systems of more than two components. It is suggested that the activity gradient rather than the concentration gradient be regarded as the "driving force" in diffusion, for, since activity is successfully used instead of concentration in interpreting equilibrium, it should have like merit in interpreting the approach to equilibrium by diffusion.

Rate of Nucleation and Rate of Growth of Pearlite. F. C. Hull, R. A. Colton and R. F. Mehl. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1460: Metals Technology, 1942, vol. 9, Aug.). The authors present and discuss data on the rate of nucleation and the rate of growth of pearlite and the manner in which these are affected by the composition of the steel, the grain size, temperature and degree of homogeneity of the parent austenite. A number of methods of determining these rates are described and the results given for a series of ten steels containing carbon in the range 0·57–1·10%. The conclusions drawn were: (1) The rate of growth remains constant with time during isothermal transformation; (2) the rate of nucleation increases with time; (3) the rate of growth is unaffected by variations in austenite grain size and in the austenite heterogeneity; the rate of nucleation, on the other hand, is very sensitive to these factors; (4) the products of deoxidation with aluminium have a very minor effect on the rate of nucleation per unit of grain-boundary area; and (5) the effect of austenite heterogeneity upon the rate of transformation and upon the rate of nucleation is much more marked at high reaction temperatures than at temperatures near the knee of the S-curve.

CORROSION OF IRON AND STEEL

(Continued from pp. 33 A–36A)

Laboratory Tests on the Progress of Corrosion of Steel Plate Alternately in Contact with Water and Petrol. J. Morsing. (Statens Provningsanstalt, 1942, Report No. 87, pp. 3–35). (In Swedish). The author reports on a series of laboratory tests carried out at the Government Testing Institute in Stockholm in order to study the corrosion of steel plate subjected to the attack of water and petrol alternately, as may occur on the internal surface of tanks in which petrol is stored above water. Specimens of ordinary mild steel plate 6 mm. thick were used. The tests were carried out in glass

jars in such a manner that the lower halves of the specimens were in water during the whole test period, and the upper half was alternately in water and petrol over periods of 1 to 4 weeks; the gas space above the petrol was connected to atmosphere by small openings. The amount of corrosion was judged by loss-in-weight determinations and by measuring the depth of the pits. When filling up and emptying the glass jars the oxygen dissolved in the water was determined by the Winkler method, and the dissolved rust-forming oxygen in the petrol by a colorimetric method described in detail in the second part of the Report.

Petrol of ordinary commercial quality contains at normal temperatures 50–90 mg./litre of dissolved oxygen which corrodes steel, whereas water contains about 10 mg./litre. When petrol is stored above water it serves as a source of oxygen supply and, when the oxygen-content of the water is low, the latter absorbs it from the former. Thus, petrol contributes in a high degree to the corrosion of steel in contact with both petrol and water. The pitting is greatest on that part of the surface which is alternately covered with petrol and water, because the small drops of water which adhere to the plate absorb oxygen from the surrounding petrol, and this oxygen promotes the corrosion which began underneath the drops of water. In favourable conditions the depth of the pits increases by about 1 mm. a year. Satisfactory protection of the steel plate for at least two years is obtained by applying two coats of special paint to the surface, which must first be cleaned by sand-blasting. The amount of oxygen dissolved in the petrol can be considerably diminished by adding oxgen-absorbing agents such as pyrogallol, and this greatly reduces the rate of corrosion. The dissolved oxygen can be almost entirely eliminated by passing an inert gas such as nitrogen through the petrol. The tests described should not be considered as complete, but rather as indicating the lines for further research.

A Method of Investigating the Rate of Corrosion of Steel. S. Johansson. (Jernkontorets Annaler, 1941, vol. 125, No. 11, pp. 599–614). (In Swedish). The author refers to his earlier paper describing a sensitive method of determining the rate of corrosion of steel in such manner that the dissolved iron was kept in solution (*see* Journ. I. and S.I., 1941, No. I., p. 193 A). In the present paper he describes in detail the procedure for carrying out such tests, and discusses the results obtained with a variety of plain and alloy steels. Special attention is given to the influence of (*a*) agitating the solution during the test, (*b*) the concentration of the electrolyte, (*c*) different electrolytes and (*d*) the pH value of the solution.

Corrosion of Steel by Dissolved Carbon Dioxide and Oxygen. G. T. Skaperdas and H. H. Uhlig. (Industrial and Engineering Chemistry, Industrial Edition, 1942, vol. 34, June, pp. 748–754; Steam Engineer, 1942, vol. 12, Oct., pp. 3–4). In order to study the corrosion of central-heating radiators and of the condensate return

pipe lines of these systems, the authors carried out laboratory tests on specimens of 0·15% carbon steel in water at 60° and 90° C. containing dissolved carbon dioxide up to 25 c.c. per litre and dissolved oxygen up to 4 c.c. per litre. Solutions at 60° C. containing oxygen caused six to ten times as much corrosion as carbon dioxide in the same molar concentrations. At 90° C. the increase in the corrosiveness of carbon dioxide was relatively greater than the corresponding increase for oxygen by approximately 20%. Corrosion by a solution containing both carbon dioxide and oxygen was 10–40% higher than the sum of the corrosion by the dissolved gases acting separately. The increase in corrosion observed was greater at low oxygen/carbon-dioxide concentration ratios.

The Corrosion Resistance Afforded by Bright Dipped Cadmium Coatings. G. Soderberg. (Electrochemical Society, Oct., 1942, Preprint No. 82–14). The author reports on some corrosion tests on cadmium-plated specimens of 5-in. × 2-in. steel sheet in which a comparison was made of the corrosion resistance of specimens in the as-plated condition with that of specimens which, after plating, rinsing and drying, were dipped for 3 sec. in a brightening solution containing chromic and sulphuric acids. The tests proved that although the brightening solution removed 0·00022 mm. of plating, the corrosion resistance of cadmium coatings more than 0·0025 mm. thick was unaffected, whilst that of coatings 0·0075 mm. thick was definitely improved by the brightening treatment.

ANALYSIS

The Theory and Practical Application of Polarographic Analysis. G. H. Jeffery. (Sheet Metal Industries, 1942, vol. 16, Oct., pp. 1525–1530, 1549). The author gives a comprehensive explanation of the theory of polarographic analysis, describes the apparatus, the preparation of the cells, the calibration of a polarograph and discusses its applications.

Some Modern Methods of Metallurgical Analysis. F. W. Haywood. (Metallurgia, 1942, vol. 26, Aug., pp. 117–120, 148). The author describes the principles and applications of the Spekker Steeloscope and the Spekker photo-electric absorptiometer. These instruments have been described in detail previously (*see* Journ. I. and S.I., 1941, No. I., p. 79 A, and 1942, No. II., p. 227 A).

Determination of Carbon in Steel. (Sheet Metal Industries, 1942, vol. 16, Oct., p. 1488). Owing to the war the Ströhlein apparatus for making rapid determinations of carbon in steel is no longer imported into Great Britain. In this article a brief description is given of an improved apparatus of the Ströhlein type now available in this country, with which an estimation of the carbon accurate to 0·01% can be made in about 1 min.

Short Cuts for Determining Sulphur and Molybdenum in Alloy Steels. E. R. Vance. (Steel, 1942, vol. 111, Aug. 31, pp. 56–58). The author describes rapid and reliable procedures for making sulphur and molybdenum determinations in alloy steels.

The Determination of Low Molybdenum Contents in Ores. (Jernkontorests Annaler, 1941, vol. 125, No. 12, pp. 697–704). (In Swedish). Methods of determining the molybdenum contents of ores when the amount present may be as low as 0·20% are discussed and details are given of a reliable method developed by E. Hammarberg.

The Determination of Volatile Matter in Coal and Coke. R. A. Mott. (Fuel in Science and Practice, 1942, vol. 21, Sept.–Oct., pp. 102–112). The author presents an account of the experimental work of the Analysis Sub-Committee of the British Standards Institution in establishing a standard method of determining the volatile matter in coal and coke.

BOOK NOTICES

Foster, P. F. "*The Mechanical Testing of Metals and Alloys. The Theory and Practice of Standardised Mechanical Testing.*" Third Edition. 8vo. pp. ix + 317 + 23. Illustrated. London, 1942: Sir Isaac Pitman & Sons, Ltd. (Price 18*s*.)

Although there is a considerable amount of useful information in this book, the subject-matter is not new.

The chapters dealing with the better-known testing machines are, in general, adequate, and, besides containing descriptions of the various testing machines, also deal with testing procedure.

A chapter is devoted to extensometers and recorders, and it is disappointing not to find a description of the Lindley extensometer, as this is so widely used, and is such a simple and serviceable piece of apparatus.

Only three pages are devoted to creep testing, and so obviously are of little use to anyone.

The determination of hardness at high temperatures is, however, still more inadequately considered, and only four and a half lines are devoted to it. The statement in these four and a half lines that a diamond is necessary in this test is not correct.

J. Ferdinand Kayser.

Work Projects Administration: "*Tables of the Moment of Inertia and Section Modulus of Ordinary Angles, Channels, and Bulb Angles with Certain Plate Combinations.*" Prepared by the Federal Works Agency, Works Projects Administration for the City of New York, as a Report of Official Project No. 165-2-97-22, Mathematical Tables Project. 4to. pp. xiii + 197. New York, 1941. London: Scientific Computing Service, Ltd. (Price £1).

This publication consists of a series of mathematical tables prepared by the Mathematical Tables Project conducted by the Works Projects

Administration for the City of New York, under the sponsorship of the National Bureau of Standards. The tables give the moment of inertia and the section modulus of ordinary angles, (heel-to-plate and toe-to-plate) in sizes ranging from 2 × 2 to 8 × 8 in., of channels from 3 × 1½ to 18 × 4 in. and of bulb angles from 4 × 3½ to 10 × 3½ in. with different plate combinations. In addition there are Schedules giving the properties of plates, ordinary angles, channels and bulb angles.

The tables, which are well set out and reproduced by a photo-offset process, should be useful to engineers, especially those engaged in steelwork construction.

BIBLIOGRAPHY

ALTHOUSE, A. D., C. H. TURNQUIST, G. E. TABRAHAM and B. E. OTT. "*Modern Welding Practice.*" Pp. 412. Chicago: Goodheart Willcox Co.

AMERICAN IRON & STEEL INSTITUTE. Contributions to the Metallurgy of Steel. 8vo.

No. 6. "*Selection and Conservation of Alloying Elements Used in Steel.*" Pp. 57. Illustrated.

No. 7. *The National Emergency Steels. NE* 8000 *Series.* Pp. 50. Illustrated.

No. 8. *Supplementary National Emergency Steels NE* 9400, 9500, 9600 *Series.* Pp. 89. Illustrated.

ANSLEY, A. J. "*Temperature Control.*" Pp. viii + 127. London: Chapman & Hall, Ltd. (Price 13*s.* 6*d.*)

BATLEY, R. L., and E. G. BARBER. "*Boiler Plant Technology.*" London: Sir Isaac Pitman & Sons, Ltd. (Price 15*s.*)

BUERGER, M. J. "*X-Ray Crystallography.*" 8vo, pp. 531. Illustrated. New York, 1942: John Wiley and Sons, Inc. (Price $6.50.)

COLER, M. A. "*Aircraft Engine and Metal Finishes.*" Pp. 128. Illustrated. New York: Pitman Publishing Corporation. (Price $1.50.)

Die chemische Emissions-Spektralanalyse. 2., verb. Aufl. Teil 3. Tabellen zur qualitativen Analyse. Von W. Gerlach und E. Riedl. 8vo, pp. ix + 154. Leipzig, 1942: Johann Ambrosius Barth. (Price 6 RM.)

DIERCKS, H., and H. EULER. "*Praktische Nomographie.*" (Sonderbericht des Ausschusses für Betriebswirtschaft des Vereins Deutscher Eisenhüttenleute im NS.-Bund Deutscher Technik.) 8vo, pp. 96. Illustrated. Düsseldorf, 1942. Verlag Stahleisen, m.b.H. (Price 5 RM.)

DURNEY, W. C. "*Machine Shop Practice.*" Second Edition. 8vo, pp. 185. London, 1942: Sir Isaac Pitman & Sons, Ltd. (Price 7*s.* 6*d.*)

FRAZER, R., and O. BERTHIAUME. "*Practical Aircraft Sheet Metal Work.*" 4to, pp. 193. New York and London, 1942: McGraw Hill Book Co., Inc. (Price 21*s.*)

HATFIELD, W. H. "*Lecture on Rust-, Acid- and Heat-Resisting Steels.*" (Institute of Chemistry.) 8vo, pp. 48. Illustrated. London, 1942: Institute of Chemistry. (*See* p. 63 A).

HAUGHTON, J. L. "*Bibliography of the Literature Relating to Constitutional Diagrams of Alloys.*" Institute of Metals Monograph and Report, Series. 8vo, pp. 163. London, 1942: The Institute of Metals. (Price 3*s.* 6*d.*)

HILL, F. T. "*Materials of Aircraft Construction.*" New Edition. 8vo, pp. 461. London, 1942: Sir Isaac Pitman and Sons, Ltd. (Price 20*s.*)

HIRST, H. "*X-Rays in Research and Industry.*" 8vo, pp. 96. Illustrated. Melbourne, 1942: Tait Publishing Co. Pty., Ltd. (Price 7*s.* 6*d.* cloth; 5*s.* paper.)

KOLTHOFF, L. M., and V. A. STENGER. "*Volumetric Analysis.*" Second rev. ed., Vol. 1. "*Theoretical Fundamentals.*" 8vo, pp. xv + 309. New York, 1942: Interscience Publishers, Inc.; London: The Imperia Book Co., Ltd. (Price $4.50.)

LANZ, H. "*Die Entwicklung des Gusseisens zum Lanz-Perlit.*" (Lanz-Forschungsdienst, Bd. 1.) 8vo, pp. xii + 393. Illustrated.

LINCOLN ELECTRIC CO. "*Procedure Handbook of Arc Welding Design and Practice.*" Seventh Edition. Cleveland, Ohio and Welwyn Garden City, Herts: Lincoln Electric Co. (Price 10*s.*)

MIES, O. "*Metallographie.*" Grundlagen und Anwendungen. 2., verb. Aufl. (Werkstattbücher für Betriebsbeamte, Konstrukteure und Facharbeiter. Hrsg. H. Haake. H. 64.) 8vo, pp. 68. Berlin, 1942: Springer-Verlag. (Price 2 RM.)

MOORE, H. F., H. F. GONNERMAN and J. O. DRAFFIN. "*Textbook of the Materials of Engineering.*" Sixth Edition. 8vo, pp. 454. New York, 1942: McGraw Hill Book Co., Inc.; London: McGraw Hill Publishing Co., Ltd. (Price 28*s.*)

MOYER, J. A. "*Welding.*" Pp. 184. New York: McGraw Hill Book Co., Inc. (Price $2.25.)

MÜLLER, E. "*Die elektrometrische (potentiometrische) Massanalyse.*" 6., verb. u. verm. Aufl. 8vo, pp. xx + 294. Illustrated. Dresden und Leipzig, 1942: Theodor Steinkopff. (Price 16 RM.)

MÜLLER, M. "*Die Dauerfestigkeit geschweisster, gebrauchter Eisenbahnschwellen unter besonderer Berüchsichtigung der elektrischen Abschmelzstumpfschweissung.*" (Hannover (Techn. Hochschule), Dr.-Ing. Diss.). 4to, pp. 61. Illustrated.

NATIONAL PHYSICAL LABORATORY. "*The Technique of Calibrating Platinum Thermocouples for Use in Liquid Steel.*" 8vo, pp. 7. Illustrated. London, 1942: H.M. Stationery Office. (Price 2*d.*) (*See* p. 55 A).

NIEZOLDI, O. "*Ausgewählte chemische Untersuchungsmethoden für die Stahl- und Eisenindustrie.*" 3., verm. u. verb. Aufl. 8vo. pp. viii + 184. Berlin, 1942: Springer-Verlag. (Price 6.90 RM.)

RAPATZ, F. "*Die Edelstähle.*" 3., stark umgearb. Aufl. unter Mitwirkung von H. Krainer und J. Frehser. 8vo, pp. v + 482. Illustrated. Berlin, 1942: Springer-Verlag. (Price 22.80 RM.)

SCHUMACHER, F., and N. THAMM. "*Die nutzbaren Minerallagerstätten von Deutsch-Ostafrica.*" (Mitteilungen der Forschungsstelle für Kolonialen Bergbau an der Bergakademie Freiberg Nr. 1.—Mitteilungen der Gruppe Deutscher Kolonialwirtschaftlicher Unternehmungen. Bd. 6.) 8vo, pp. ix + 142. Illustrated. Berlin, 1941: Walter de Gruyter & Co. (Price 12 RM.)

"*Stahlleichtbau.*" Eine Aufsatzfolge. Hrsg. Beratungsstelle für Stahlverwendung. Heft. 1. 8vo, pp. 82. Düsseldorf, 1941: Beratungsstelle für Stahlverwendung.

TRINKS, W. "*Industrial Furnaces.*" Vol. II. 2nd edition. 8vo, pp. xiii + 351. New York, 1942: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd. (Price \$5.)

WEBER, ROBERT L. "*Temperature Measurement and Control.*" 8vo, pp. x + 430. Illustrated. Philadelphia, 1941: The Blakiston Co.

WORKS PROJECTS ADMINISTRATION. "*Tables of the Moment of Inertia and Section Modulus of Ordinary Angles, Channels and Bulb Angles, with Certain Plate Combinations.*" Prepared by the Federal Works Agency, Work Projects Administration for the City of New York as a Report of Official Project No. 165–2–97–22. Mathematical Tables Project. 4to, pp. xiii + 197. New York, 1941: London: Scientific Computing Service, Ltd. (Price £1.) (*See* p. 69 A).

YOUNG, G. B. "*Magnetic Crack Detection. Notes on Working Principles and Use of Apparatus.*" 8vo, pp. viii + 60. Illustrated. London, 1942: Charles Griffin & Co., Ltd. (Price 2*s*. 6*d*.)

ZWIKKER, C. "*Technische Physik der Werkstoffe.*" 8vo, pp. vii + 230. Illustrated. Berlin, 1942: Springer-Verlag. (Price 24 RM.)

REFRACTORY MATERIALS

(Continued from pp. 1 A–2 A)

Production and Properties of the Commercial Magnesias. M. Y. Seaton. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1496 : Mining Technology, 1942, vol. 6, July). The author discusses the production, properties and applications of magnesia in the United States. As far as the finished products are concerned, those with less than about 80% of magnesium oxide are not included in the paper. Particulars are given of the magnesite industries of California, Washington, and Nevada, and the process of recovering magnesia from seawater and from bittern is described (bittern is the liquor left after salt has been recovered from sea-water by evaporation).

The Action of Chlorine on Refractory Materials. Part I. Preliminary Experiments with some Typical Commercial Products. L. R. Barrett, F. H. Clews and A. T. Green. (Transactions of the British Ceramic Society, 1942, vol. 41, Aug., pp. 191–196). The occasional occurrence of significant amounts of chlorides, notably sodium chloride, in coal raises the question of the action of chlorine and hydrochloric acid on refractories when such coal is burnt or carbonised. Experiments on this problem are reported in this paper. Samples of typical refractory materials and a fired blue brick clay were exposed for periods of 2 hr. at 1000° C. and the losses in weight determined. Two bricks (one containing 23·9% of carbon and the other a clay-bonded silicon-carbide brick) suffered the greatest loss, silicon tetrachloride being formed. The magnesite and chrome bricks and the blue brick clay were markedly attacked. The refractoriness of a diatomaceous insulating material was increased from Seger cone 17 to 27 by treatment for 10 hr. with chlorine at 1000° C.

The Action of Chlorine on Refractory Materials. Part II. Experiments on the Action of Chlorine on Certain Oxides, Silicates and Spinels. H. M. Richardson, F. H. Clews and A. T. Green. (Transactions of the British Ceramic Society, 1942, vol. 41, Aug., pp. 196–205). The conversion of various oxides into chlorides by the action of chlorine at 1000° C. has been studied. The following is the approximate order of reactivity : Iron oxide > magnesia > lime > titanium dioxide > zirconia > alumina > silica. More complex compounds containing these oxides, such as various silicates and spinels, were less reactive than the free constituent oxides.

Apparatus for Measuring Thermal Conductivity of Refractories. C. L. Norton, jun. (Journal of the American Ceramic Society, 1942, vol. 25, Nov., pp. 451–459). The author refers to the need for standardising apparatus and procedure for determining the

thermal conductivity of refractory bricks, and describes an apparatus developed at the Babcock and Wilcox laboratories in the United States. In this apparatus a constant-temperature gradient is maintained across the specimen brick by supplying heat to one face with six electric heating units; the opposite face of the brick rests on copper calorimeters through which a flow of water is maintained. The rise in temperature of the water and the amount of water flowing in a fixed time interval are measured, and from these data the thermal conductivity can be calculated. Test runs covering a very wide temperature range can be made in three or four days. Some results obtained with insulating bricks and dense firebricks are given.

Control Testing for Consistency of Refractory Mortars. E. C. Petrie and D. W. Kocher. (Journal of the American Ceramic Society, 1942, vol. 25, Nov., pp. 459–463). The authors discuss methods of determining the consistency of refractory mortars. They found the flow-trough method and the Hommel viscosimeter to be unsuitable for testing mortars with a normal water content. Two modified forms of the Vicat needle, which is used in the pottery industry to determine the plasticity of clays, were found to give satisfactory and reproducible results. This form of apparatus consists of a brass rod held vertically in a guide to which a scale and clamping screw are attached; an aluminium or stainless-steel plunger is fixed to the bottom of the rod, and a suitable weight is screwed on the top. A small container is filled with the mortar to be tested, the sample being thoroughly mixed and free from air bubbles. The sample is placed on the stand with the tip of the plunger just touching the surface. The clamping screw is released, and the distance the plunger sinks into the mortar in 30 sec. is a measure of its consistency. The apparatus is easy to operate and clean; the readings are obtained quickly and can be readily evaluated.

Hot-Face Insulation. T. S. Pearson. (British Steelmaker, 1942, vol. 8, Dec., pp. 348–352). The author discusses the advantages and limitations of bricks for insulating the hot face of furnace walls, the purpose of which is to reduce the amount of heat absorbed by the furnace structure. There are two types of these bricks available, and these are suitable for maximum hot-face temperatures of 1200° and 1350° C. respectively. Their heat-absorption capacity is about one-third of that of firebricks. The advantage of using them is greater with intermittently working furnaces than with continuous furnaces, but with the latter a greatly improved response to variations in fuel control is at once apparent.

Heat Insulation and Its Problems. W. Goldsbrough and S. G. Throssell. (British Steelmaker, 1942, vol. 8, Dec., pp. 354–358). The authors show how to calculate heat balances for furnaces with particular reference to the advantages of using insulating bricks.

PRODUCTION OF IRON

(Continued from pp. 41 A–43 A)

Taylor-Wharton Started Making Iron before United States Was Born. (Steel, 1942, vol. 111, Oct. 19, pp. 53–55, 104, 105). A short illustrated account is given of the history of the Taylor-Wharton Iron & Steel Co., High Bridge, New Jersey. This company now has an extensive iron and steel works on the site where William Allen in 1742 erected a furnace close to an existing forge.

The Determination of Certain Characteristic Data from the Composition of Blast-Furnace Flue Gases. A Sarkisyants. (Iron and Steel Institute, 1943, Translation Series, No. 119). An English translation is presented of a paper which appeared originally in Stal, 1939, No. 8, pp. 1–8 (*see* Journ. I. and S.I., 1940, No. I., p. 274 A).

Exploding the "Sponge Iron" Myth in Modern Steelmaking Practice. F. F. Foss. (Steel, 1942, vol. 111, Oct. 12, pp. 100–103, 115, 116). The author discusses the possibilities of producing direct from ore a sponge iron suitable as a substitute for scrap in open-hearth steelmaking. The Krupp-Renn (German) and the Höganäs (Swedish) processes are dealt with in particular. Practical experience with the Krupp-Renn product has shown that it is less costly to desulphurise the sponge lump in the furnace than in the open-hearth. In the Höganäs process a concentrate containing about 71% of iron from Gellivare magnetic iron ore is packed with a locally produced coal in large crucibles and heated to 1800° F. so as to produce cylindrical lumps of sponge iron containing 96% of iron and only 0·015% of sulphur and 0·013% of phosphorus. Under the exceptionally favourable local conditions the sponge iron produced at Höganäs is profitably used for making high-grade steel. In general, it can be said that regular sponge iron cannot be used in the open-hearth or electric furnace on an equal basis with iron scrap either technically or economically, even under emergency conditions.

Sintered, Forged and Rolled Iron Powders. C. G. Goetzel. (Iron Age, 1942, vol. 150, Oct 1, pp. 82–92). The author reports the results of tests on specimens of iron prepared by the powder-metallurgy process in three different ways. Two types of powder were used, one made from sponge iron reduced from mill-scale with hydrogen, the other an electrolytic iron of 99·8% purity. The three different treatments were: (*a*) Pressing and sintering 1–2 hr. at 1000–1300° C., sometimes with a second pressing and annealing; (*b*) pressing, sintering and hot-forging; and (*c*) pressing, sintering and cold-rolling. Tables of test data as well as micrographs are presented. If iron compacts are twice pressed and heated and very

pure iron powders are used, a density of 98% of the normal can be obtained. The limit of proportionality and the elastic limit are, however, 10% below normal. The elongation and reduction-of-area values were one-half to two-thirds of the normal. The finer the powder, the higher were the strength values, whilst the coarse powders gave better ductility. Hot-forging, even with only 25% reduction, materially improved all the properties, so too did cold-rolling. With this after-treatment the tensile strength and ductility were brought within normal limits, the modulus of elasticity to 65–90% of the normal and the elongation and reduction of area to 75% of the customary values.

FOUNDRY PRACTICE

(Continued from pp. 43 A–46 A)

The Development and Control of Engineering Gray Cast Irons. R. A. Flinn and D. J. Reese. (Transactions of the American Foundrymen's Association, 1942, vol. 49, Mar., pp. 559–602). The authors present a comprehensive survey of factors affecting the structure of grey cast iron and of the relation between the structure and the strength properties. The factors affecting the graphite and the matrix are dealt with separately, and it is shown how the various changes in structure can be produced and controlled.

Practical Time Study Measurements for Foundry Operations. P. Carroll, jun. (Transactions of the American Foundrymen's Association, 1942, vol. 49, Mar., pp. 503–523). The author proposes a method for obtaining time-study data in jobbing foundries. This method is based on breaking down a particular operation into (*a*) constant elements which are the same for every job regardless of size, and (*b*) variable elements which are dependent on the type and size of casting being made.

The Foundry in Mexico. H. H. Miller. (Western Hemisphere Foundry Congress: Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 165–171). The author gives a concise account of the problems and work of the foundrymen in Mexico, pointing out the diversity of the castings required, the scarcity of scrap metals and of skilled pattern-makers for intricate pump castings.

Comments on the Brazilian Foundry Industry. H. A. Hunnicutt. (Western Hemisphere Foundry Congress: Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 172–179). The author gives a general survey of the foundry industry of Brazil, and describes some of the changes caused by the cessation of imports of foreign machinery and steel products. He compares Brazilian cast irons with those of the United States, and

relates what progressive foundrymen are doing in the fields of sand control, cupola operation and metallography. There are two technical research associations supplying the industry with information and test data.

A Multipurpose Brazilian Foundry. L. D. Villares. (Western Hemisphere Foundry Congress: Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 180–184). The author describes the activities of Pirie, Villares & Cia., Ltda., a Brazilian firm that has been making passenger and freight elevators for twenty-two years. Their equipment now includes one 3-ton direct-arc electric furnace, two 15-in. and one 24-in. cupolas, sand-mixers and four moulding machines. They now make high-quality alloy cast iron, cast steel, steel forgings and tool-steel bars.

Some Aspects of the Cast Iron Practice in Brazil. M. Siegel. (Western Hemisphere Foundry Congress: Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 185–214). The author describes foundry practice in Brazil with particular reference to moulding sands, core preparation and pattern-making. He explains the functions and activities of the *Instituto de Pesquisas Technologicas* (Institute for Technical Research), discussing the successful results obtained by its foundry department.

Casting High-Speed Steel. W. F. Sherman. (Iron Age, 1942, vol. 150, Sept. 24, pp. 41–44). The author describes the plant, layout and processes at the steel foundry of the Gorham Tool Co., Detroit, where high-speed steel tools are made. There are two 200-lb. and one 30-lb. induction furnaces and two 50-lb. arc furnaces. The steel produced contains molybdenum 8%, chromium 4%, vanadium 2%, cobalt 8% and boron 1%. The annealed castings are easily machined to the desired shape, leaving only sufficient tolerance for finish-grinding after heat treatment. Both box-sand moulds and centrifugal casting machines are used, and some cutters are cast with the teeth which only require finish-grinding.

Atmospheric Pressure and the Steel Casting—A New Technique in Gating and Risering. H. F. Taylor and E. A. Rominski. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 215–251). **Applies Atmospheric Pressure to Secure Sound Castings.** H. F. Taylor and E. A. Rominski. (Foundry, 1942, vol. 70, Oct., pp. 74–77, 161–164). The authors describe how risers can be arranged in moulds for steel castings so that their effect either assists or counteracts that of the atmospheric pressure in filling up shrinkage cavities. The system known as "blind risering" is advocated for certain types of casting such as valve-flanges. The blind riser is one covered with a cope, and it has been found advantageous to permit the pressure of the atmosphere to act on the covered riser by building in a permeable sand core leading from the top of the riser to atmosphere. In such cases the casting mav extend well above the level of the riser and, as soon as shrinkage takes place in the casting, the pressure of the atmosphere acts on

the riser through the sand core, and this feeds the casting. With this technique the riser is between the sprue and the casting, so that the feed-metal is hotter than it would be if the riser were filled last.

The Use of Models in Improving Steel Casting Practice. S. W. Brinson. (Transactions of the American Foundrymen's Asssociation, 1942, vol. 49, Mar., pp. 480–494). The author demonstrates, by describing and illustrating examples, that in the making of large steel castings it is well worth while having a model of the casting made. Such a model makes it easy to determine how to make the patterns, the position of the pattern in the mould and the best location for gates and risers. The examples given relate to turbine castings.

Progress Report of Sintering Test Subcommittee, Foundry Sand Research Committee. (Transactions of the American Foundrymen's Association, 1942, vol. 49, Mar., pp. 552–558). The Foundry Sand Research Committee of the American Foundrymen's Association appointed a sub-committee to report on the reasons for the widely differing results obtained with the standard sintering test for moulding sand and to suggest revisions to the test. In this sintering test a strip of platinum $2 \times \frac{3}{8} \times 0{\cdot}002$ in. is placed round the curved surface of a cylindrical specimen of the sand; a load of 170 g. is applied and a series of tests is made by electrically heating the strip to temperatures which increase in 25° C. stages. The platinum is kept in contact with the sand at the testing temperature for 4 min. The strip-holder and strip are then lifted off and it is noted whether or not the strip adheres to the specimen and makes a V when lifted. The lowest temperature at which the platinum ribbon adheres to the specimen is known as the "A" sintering point of the sand. The "B" sintering point is the lowest temperature at which traces of fusion are seen at 20–25 diameters magnification. A detailed procedure for making these tests is proposed.

Progress Report on Investigation of Effect of High Temperatures on Steel Sands. No. 1.—Part 2.—Expansion-Contraction Tests. G. W. Ehrhart. (Transactions of the American Foundrymen's Association, 1942, vol. 49, Mar., pp. 640–645). This is an account of part of the work on steelfoundry sands organised by the Foundry Sand Research Sub-Committee of the American Foundrymen's Association; in it the results of expansion-contraction tests on a number of American steelfoundry moulding-sand mixtures are presented.

Progress Report on Investigations of Effect of High Temperatures on Steel Sands. No. 2.—Comparison of Specimen Sizes. J. R. Young. (Transactions of the American Foundrymen's Association, 1942, vol. 49, Mar., pp. 646–685). In view of the fact that some laboratories engaged in testing moulding sands use specimens $1\frac{1}{8}$ in. in dia. × 2 in. long and others specimens 2 in. in dia. × 2 in. long, the Foundry Sand Research Sub-Committee (*see* preceding abstract)

carried out comparative tests on the two sizes. Naturally-bonded and synthetically-bonded sands for steel castings were prepared and the two sizes of specimen were tested for (*a*) green permeability, (*b*) green compression, (*c*) green deformation, (*d*) dry permeability, (*e*) dry compression, (*f*) hot strength and (*g*) expansion when slowly and rapidly heated. The results are reported in tables and as curves. The room-temperature properties of 2 × 2-in. specimens rammed by the standard A.F.A. (American Foundrymen's Association) method were very different from those obtained with $1\frac{1}{8}$ × 2-in specimens rammed with the Dietert rammer. In high-temperature tests $1\frac{1}{8}$ × 2-in. specimens gave higher hot-strength properties than 2 × 2-in. specimens, but there was substantially no difference in the amount of free expansion.

Measurement of Free Expansion of Sand Mixtures at High Temperatures. G. W. Ehrhart. (Transactions of the American Foundrymen's Association, 1942, vol. 49, Mar., pp. 687–710). The author reports on an investigation of the expansion and contraction of moulding-sand mixtures when the sand specimen was free to change its length without any load on it. A mechanical and an optical apparatus for measuring the changes in length are described. The following results were observed: (1) The total expansion was independent of the amount of bonding material, moisture and degree of ramming; (2) the total contraction was less than the total expansion; (3) the total contraction was less for fireclay-bonded mixtures than for bentonite-bonded mixtures; (4) when heated slowly enough to prevent cracking, there was no difference in the expansion and contraction of $1\frac{1}{8}$-in. and 2-in. specimens; (5) $1\frac{1}{8}$-in. specimens could be heated at a faster rate than the 2-in. specimens without cracking; (6) on reheating a specimen, the expansion was found to be less than on the first heating; (7) on reheating, the specimen contracted to very nearly the same length as before reheating; and (8) when a specimen which had been previously heat-tested was broken up, tempered without adding any bond, and made into a new specimen, the expansion was found to be the same as that of the original specimen when first heated.

Testing of Foundry Sand and Its Coordination with Molding Results. J. J. Boland. (Transactions of the American Foundrymen's Association, 1942, vol. 49, Mar., pp. 730–746). The author gives an account of the development of methods of sand control by the Griffin Wheel Co., a firm producing chill-cast railway wagon wheels at twelve plants in the United States. Methods of recording defects are also described, and statistics on losses due to moulding defects show that considerable improvement has taken place with the increased application of methods of sand control.

Designing for Foundry Production. E. Geiger. (Western Hemisphere Foundry Congress: Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 149–164). The

author makes recommendations on the design of iron and steel castings relating to tolerances, amount of draft to facilitate withdrawal of the pattern, the position and size of lugs, and changes in section.

Design of Core Boxes and Driers for Core Blowing Machines. O. A. Van Sickle. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 260–263). The author discusses the design of core-blowers, which are machines for blowing sand into core-boxes for the rapid production of cores. Some details on the position of the parting line of the box and the sizes of sand-nozzles and vent-holes are given.

The Quasi-Bessemerising Process. W. S. Williams. (Iron and Steel, 1942, vol. 16, Nov., pp. 34–36, 45). The author describes a special process for making ingot moulds of hematite iron. The difficulties encountered in making ingot moulds are largely due to the formation of kish in and on the surface of molten hematite iron. In principle, the method described consists of blowing air into the molten metal in the sand-mould, hence the name "Quasi-Bessemerising." The apparatus required is simple, and consists of the tubes and fittings for supplying a regulated flow of compressed air at 15 lb. per sq. in. through a $\frac{1}{2}$-in. steel tube introduced into the highest part of the mould near a riser head. The air passes into the molten metal and emerges accompanied by impurities contained in the iron; the air is blown in irregular pulses which cause large masses of iron to beat upon the walls of the sand-mould; this vibration can be both heard and felt. The mechanism of the process is explained and the results of tests on ingot moulds made in the manner described are given.

Guns Cast Centrifugally. C. T. Harris, jun. (Machinist, 1942, vol. 86, Nov. 21, pp. 822–823). A brief description is given of the plant and process used at one of the United States arsenals for the centrifugal casting of gun-barrels of up to 6-in. bore. The steel is melted in coreless induction furnaces, the quantity in a given furnace being the exact amount required to cast one gun. The mould is rotated at high speed, and a pouring box is placed at one end; the whole furnace is brought up to the end of the mould on a special carrier, and the steel is teemed while the mould rotates. After a short interval the mould-cover is unbolted and a hydraulic ram pushes out the red-hot casting.

PRODUCTION OF STEEL

(Continued from pp. 46 A–52 A)

Alloy Steel. (Canadian Metals and Metallurgical Industries, 1942, vol. 5, Sept., pp. 262–264). A brief description is given of the

sequence of processes at a Canadian steelworks where the melting-shop capacity has recently been increased by putting in four 25-ton Héroult electric furnaces.

The Utilised Heating Surface of Checkers in the Regenerator Chambers of Open-Hearth Furnaces. K. Guthmann. (Stahl und Eisen, 1942, vol. 62, Sept. 10, pp. 774–779). The author reports the results of some tests carried out by the "Wärmestelle Düsseldorf" on three open-hearth furnaces when certain measures for improving the efficiency of the regenerator chambers were tried. A rectangular plate which could be raised and lowered was fitted into the reversing flue to the air-chambers. It was found that alternating the position of this plate had a very marked effect on the efficiency of the chambers by changing the utilised heating surface of the checkers; the best results on one furnace were obtained with the plate lowered so as to reduce the open cross-section of the flue by one-third. Increased production with more efficient utilisation of the fuel was obtained in each case by fitting a throttle-plate in the flue and running trials to find the optimum setting for it. Data on the construction of the checkers and the changes in the air and flue-gas temperatures are given in tables and graphs.

A Review of Basic Open-Hearth Practice at an Australian Plant. R. L. Knight. (Iron and Steel Institute, 1943, this Journal, Section I.). The author gives a comprehensive description of the plant and practice at the steelworks of Australian Iron and Steel, Ltd., Port Kembla. The plant is situated 15 miles by rail from several collieries owned by the company; the limestone is brought 70 miles by rail from Marulan; red hematite ores, low in phosphorus, are shipped from the Whyalla deposits to Port Kembla, which is about 1070 miles. The open-hearth department consists of seven fixed furnaces varying from 160 to 280 tons capacity and a 1200-ton hot-metal mixer, the latter receiving metal from 70-ton transfer ladles filled from 120-ton ladles hauled from the blast-furnaces. The open-hearth furnaces are fired with either tar and coke-oven gas or producer gas and coke-oven gas. They all comply with accepted modern standards relating to water-cooling, and are equipped with modified Blair ports and water-cooled straight-line gates and valves. The tar is burned at 40 lb. per sq. in. and 200° F. with steam for atomisation at 60–80 lb. per sq. in. and 325° F. The outstanding features of the furnace practice are the high hot-metal/scrap ratio, the heavy ore charge (448 lb. per ton) and the low flux rate. The furnaces are therefore subject to violent and protracted ore boils, resulting in a heavy carry-over of solid particles in the waste-gas stream; in spite of this, three of the furnaces have produced ingots at a rate exceeding 21 tons per hr. During ten years' working, improvements in design enabled the 230-ton and 280-ton fixed furnaces to be built which can carry such burdens continuously for campaigns exceeding 36 weeks. Details of these

improvements in hearth, slag-pocket and checker-chamber design are given. Five of the seven furnaces are all-basic except for the roof and downtake arches; 95%-silica bricks are used for the roofs, the life of which varies with the type of fuel; an average roof life is 370 heats on producer-gas-fired units. Comprehensive descriptions of stockyard operations; charging, melting and tapping practice; ingot-mould design and preparation; slag control; and the production of phosphorised sheet bars, of rimming steel and of alloy and forging steels constitute the last part of the paper.

Recovery of Metals from Scrap. Sir H. Hartley. (Nature, 1942, vol. 150, Nov. 21, pp. 594–597). This paper was presented at the Conference on Mineral Resources and the Atlantic Charter held recently by the Social and International Relations of Science Division of the British Association. In considering the ever-increasing consumption of metals it is obvious that serious inroads are being made into the world reserves of ores; the ultimate fate of metals in use and their recovery as scrap are therefore matters of great importance. At present iron and steel represent about 93% of the total world tonnage of metal production. About 15–20% of this is lost by rusting, and in all 35% is lost irrecoverably due to rust, dispersal and the use of iron and steel in articles from which its recovery is uneconomic. Thus 65% is left to find its way back into use, of which 25% is process scrap which does not leave the steelworks. The following measures would help towards a maximum scrap recovery: (1) The salvage of all new and as much old scrap as possible; (2) improved methods of segregating scrap of different kinds; (3) improved methods of sorting, cleaning and identifying old materials; (4) improved methods of putting scrap into suitable form for remelting; (5) arrangements to avoid the corrosion of scrap during long storage periods; (6) avoidance of the unnecessary use of alloys, which complicates scrap recovery, and the reduction of the number of alloy specifications to the minimum necessary; and (7) the re-use of old scrap by fabrication and welding.

Acid Electric Furnace Slag Control. J. Juppenplatz. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 322–334). The author discusses the relation between the viscosity of the slag in an acid-lined electric steel furnace and the slag composition. He describes a modified Herty viscosimeter in which the slag is poured into a funnel connected to a horizontal hole 12 in. long and $\frac{1}{4}$ in. in dia. in an iron chill; the distance the slag travels along the hole before solidifying is taken as a measure of the viscosity. Curves are presented showing the relation between the slag viscosity and the SiO_2, FeO, MnO and CaO contents for a $3\frac{1}{2}$-ton furnace used in a steel foundry.

Equilibria of Liquid Iron and Simple Basic and Acid Slags in a Rotating Induction Furnace. C. R. Taylor and J. Chipman. (American Institute of Mining and Metallurgical Engineers, Technical

Publication No. 1409: Metals Technology, 1942, vol. 9, Sept.). The authors report the results of a laboratory study of the equilibrium conditions between liquid iron and slags of the system (CaO + MgO)–SiO_2–FeO prepared in a rotating induction furnace similar to that described by F. W. Scott and T. L. Joseph (*see* Journ. I. and S.I., 1942, No. II., p. 104 A). The solubility of iron oxide in liquid iron under pure iron-oxide slags was redetermined, and found to differ only slightly from previously reported results. The equilibrium oxygen content of the metal at 1600° C. was taken as a measure of the activity of iron oxide in the slag. The indications were that no compound is formed between silica and ferrous oxide at 1600° C. Di-calcium silicate exists as a double molecule $(2CaO.SiO_2)_2$, and is substantially undissociated at 1600° C. On the basic side of the orthosilicate, the excess lime combines with the iron oxide to form $CaO.Fe_3O_4$ in amounts depending on the CaO available after the formation of the $2(CaO.SiO_2)_2$. The effect of magnesia was found qualitatively to be almost the same as lime for amounts up to at least 10%. The solubility of nitrogen in pure iron was checked and found to be 0·040%.

Silicon-Oxygen Equilibria in Liquid Iron. C. A. Zapffe and C. E. Sims. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1498: Metals Technology, 1942, vol. 9, Sept.). The authors describe an apparatus which they developed for studying the iron-silicon-oxygen system and the manner in which reactions in this system affect the formation of inclusions in steel. Charges of pure iron plus 97%-silicon (25 g. in all) in a silica crucible were placed in an electric furnace and held at temperatures of 1550°, 1600° and 1650° C. for periods up to 5½ hr. in a controlled atmosphere of hydrogen and water vapour. At the end of the period the crucible and contents were dropped from the furnace directly into water; the small ingot was cleaned, sectioned and analysed. Previous investigations of the iron-oxygen-silicon system at steelmaking temperature have produced data that are in disagreement; this appears to be because the equilibria cannot be expressed as a simple relationship between ferrous oxide and silicon. Assuming the existence of silicon monoxide in liquid iron, the equilibrium constants, free-energy changes, heats of reaction and entropy changes were calculated for the temperature range 1550–1650° C. in a form that allows extrapolation to other steelmaking temperatures. These results lead to an unusual interpretation of many steelmaking phenomena. For example, the total oxygen content of steels cannot be regarded as representing FeO, but must be taken into account for the alloying and deoxidising elements. As the content of the extraneous element increases, the total oxygen content of the steel will increase after some minimum has first been reached. These concepts of oxygen and oxides in steel lead to a re-evaluation of the importance of pure chemical processes in forming inclusions. The reservoir of oxygen afforded by the dissolved silicon monoxide may offer an explanation

for the otherwise unwarranted presence of oxide inclusions in some alloy steels or cast irons of notably low oxygen pressures.

FORGING, STAMPING, AND DRAWING

(Continued from pp. 52 A–53 A)

Forging Technique. R. Bennett. (Drop Forger, 1942, vol. 22, Nov., pp. 127–130). The author discusses the need for recognised standards in the British drop-forging industry and gives details of the standards of thickness tolerances, fillet radii, draft angles and flash thicknesses which have been adopted in the United States.

Stretch-Forming Speeds Aircraft Production. F. C. Hoffman. (Iron Age, 1942, vol. 150, Oct. 1, pp. 68–77). The development of forming machines which combine stretching and pressing has been described in a previous paper on stretch-forming (*see* Journ. I. and S.I., 1942, No. II., p. 140 A). In the present article some refinements in the technique to speed up production and overcome difficulties are described.

Composite Stampings Replace Forgings, Castings, Parts Machined from Solid Bar Stock. G. W. Birdsall. (Steel, 1942, vol. 111, Oct. 12, pp. 82–86, 109–111). The author describes and illustrates numerous examples of the extended use of stampings in ordnance parts which have resulted in great savings in the material used as well as in the manufacturing time and cost.

HEAT TREATMENT

(Continued from pp. 55 A–56 A)

Engineering the Treatment of 155-mm. Shell. R. F. Wilson. (Metal Progress, 1942, vol. 42, Sept., pp. 359–363). The author describes the steps taken at an American works making 155-mm. shell to determine the correct heat-treatment schedule so that the shells would have the desired physical properties. Preliminary tests on hardened and tempered specimens of the shell steel gave results from which it was decided to harden at 1500° F. and temper at 1300° F. A direct-gas-fired pusher furnace 50 ft. long holding 144 shells was used in production, and the correct temperature control was established by two thermocouples in the roof and by fixing a thermocouple with very long leads in a hole drilled in one of the shells and taking temperature readings every 4½ min. as the shell proceeded through the furnace. Some of the temperature curves are reproduced and the positioning of the fixed thermocouples in the furnace on the basis of those curves is explained.

Tool Hardening ; Practice, Not Theory. R. C. Stewart. (Metal Progress, 1942, vol. 42, Sept., pp. 378–383, 448). The author describes the hardening and tempering of tool steels and the equipment used. The relative merits of oil, water and brine for quenching are discussed and two devices for the water-quenching of wire-drawing dies are described in detail.

Heat Treating Terms Defined. (Iron Age, 1942, vol. 150, Oct. 1, pp. 103, 230–233). The definitions of heat-treatment terms proposed by the Nomenclature and Definitions Committee of the American Society for Testing Materials are presented.

Practical Gas Carburising. D. McPherson. (Machine Shop Magazine, 1942, vol. 3, Nov., pp. 84–91). The author points out that in Great Britain very large quantities of methane which might be used for gas-carburising are blown to atmosphere. He discusses some difficulties in the harnessing of the sources of supply and the relative merits of propane and butane as carburising gases. With these gases a diluent gas is required. Although water vapour is blamed for many irregularities in gas-carburising, its elimination from diluent gases is an expensive and tedious process; with a slightly carburising diluent gas it is both uneconomic and unnecessary to devise elaborate methods of dehydration. A novel and successful method of carburising using diluted town gas has been developed, in which the proportion of available methane is artificially increased by prior removal of hydrogen. A gas-carburising furnace constructed from an electric reheating furnace is described in detail. Some results attained with producer gas enriched with butane are discussed. It was found necessary to reduce the butane concentration as carburising proceeded to prevent the formation of soot on the charge. In experiments with 98% methane and charcoal producer gas it was found that the volume of methane required was appreciably greater than either butane or propane. Whereas the methane concentration could be varied by 5 % without greatly disturbing the rate of penetration of the carbon, butane and propane had to be controlled within a very narrow range.

Carburizing Characteristics of 0·20 Per Cent Carbon Alloy and Plain Carbon Steels. G. K. Manning. (American Society for Metals, Oct., 1942, Preprint No. 5). The author studied the effect of the compositions of the steels and the carburising compounds, the cooling rate, and the carburising time and temperature on the carbon content and depth of the case produced on eight different carbon and alloy steels (nickel, molybdenum, nickel-molybdenum and chromium-nickel steels), all of which contained about 0·2% of carbon. Five commercial carburising compounds on a coke and/or charcoal basis, containing sodium, calcium, barium and iron in various proportions, were used. The investigation led to the following conclusions: (1) Alloying elements, when present in the amounts generally found in carburising steels, have no marked effect on the depth of the case. (2) With some carburising compounds the presence of chromium

may lead to excessive accumulation of carbon in the surface—an effect which is to some extent counteracted by nickel. (3) The rate of cooling has no appreciable effect on the carbon content of the case. (4) The carbon content and the depth of the case increase with the carburising time and temperature.

Advances in Fast Surface Hardening. F. O. Hess. (Metal Progress, 1942, vol. 42, Sept., pp. 399–403). The author describes recent advancements in the design of burners for flame-hardening. These are designed to burn pre-mixed fuel gas and air, not acetylene and oxygen, and their use does not therefore depend on the availability of oxygen. In one type of burner the combustion zone is superheated; this zone is almost enclosed in a rectangular chamber in the bottom of which are the holes supplying the gas mixture; two opposite sides of the chamber are of ceramic material, which becomes incandescent, and thus radiates heat and accelerates the gas reactions occurring in the combustion zone; opposite the flame holes there is a constricted outlet from which the heat is emitted to the part to be hardened. Another burner is known as the radiant type. In this the flame burns in a bowl-shaped ceramic block; the surface of the bowl becomes incandescent and the rate of heat transfer from the burner to the part is thus greatly increased.

Automatic Steel-Hardening Machines. (Engineering, 1942, vol. 154, Dec. 4, p. 447 : Metallurgia, 1942, vol. 27, Nov., pp. 1–2). Two automatic "Shorter" flame-hardening machines are described and illustrated. One is for repetition work on small parts; in this machine the heating and quenching cycles are controlled by two electric clocks which are pre-set to times which have been determined by stop-watch tests. The second machine is for hardening longitudinal surfaces such as machine-tool beds, straight edges and blades.

Surface Hardening. R. Trautschold. (Steel, 1942, vol. 111, Oct. 26, pp. 64–65, 97, 98). The author describes the "Ni-Carb" process of case-hardening in which a mixture of a carburising gas and ammonia is used, and gives some details of different types of furnaces for "Ni-Carb" hardening at the works of the General Motors Corporation.

Some Observations on the Formation and Stability of Oxide Films. E. A. Gulbransen. (Electrochemical Society, Oct., 1942, Preprint 82–19). The authors studied the formation and stability of oxide films on pure electrolytic iron, 12% chromium iron and stainless steel by means of a vacuum micro-balance and a new technique of reduction with hydrogen at 350° C. Oxide films were found to form at oxygen pressures as low as 10^{-6} atm., and to be stable down to a vacuum of 5×10^{-6} mm. of mercury and at temperatures of up to 600° C. On iron passivated in 70% nitric acid a film of $1{\cdot}1 \times 10^{-6}$ g. per sq. cm. was formed, which corresponds to a thickness of 78 Å., whilst the weight of a film formed in air was $0{\cdot}44 \times 10^{-6}$ g. per sq. cm., corresponding to 29 Å. Water was shown to be adsorbed on pure iron at room temperature, and the film was

stable down to a vacuum of 5×10^{-6} mm. of mercury, but not at temperatures above 600° C. Degassed electrolytic iron was shown to react readily with oxygen at room temperature and pressures as low as 10^{-6} atm., and at 800° C. at a pressure as low as $3{\cdot}3 \times 10^{-7}$ atm. Preliminary oxidation curves of stainless steel, 12% chromium steel and electrolytic iron are presented and discussed, special reference being made to the behaviour of the two former in a vacuum of 5×10^{-6} mm. of mercury at 600° C. and in a hydrogen atmosphere at 600° and 800° C.

The Tempering of Two High-Carbon High-Chromium Steels. O. Zmeskal and M. Cohen. (American Society for Metals, Oct., 1942, Preprint No. 31). The authors examined the mechanism of the structural changes which accompany the tempering of two chromium steels (with carbon 1% and 1·5% and chromium 5% and 12% respectively) by means of magnetic, dilatometric and X-ray measurements. In general, in the hardened state the steels contained tetragonal martensite, retained austenite and undissolved carbides. During the early stages of tempering, the martensite changed from the tetragonal to the cubic form, and this was followed by precipitation of non-magnetic carbides.

The Hardening of Tool Steels. P. Payson and J. L. Klein. (American Society for Metals, Oct., 1942, Preprint No. 29). The authors studied factors affecting the hardenability of eleven commercial tool steels ranging from an unalloyed 1% carbon steel to 18/4/1 high-speed tool steel. The transformation-temperature/time curves for the steels are presented and the necessity of cooling them to low temperatures in the hardening operation before tempering is emphasised.

Practical Suggestions Concerning the Heat Treatment of Tool Steels. J. E. Erb. (Iron Age, 1942, vol. 150, Oct. 8, pp. 47–50). The author describes some of the procedures for heat-treating tools as employed at the Schenectady Works of the General Electric Co.

Heat Treating Molybdenum High-Speed Steel. W. R. Breeler and W. H. Wills. (Steel, 1942, vol. 111, Oct. 12, pp. 95–98). The authors present heat-treatment and hardness data for three types of molybdenum tool steels, the analyses of which are given below :

	Type I.	Type II.	Type III.
Carbon . . .	0·75–0·85	0·75–0·85	0·75–0·90
Tungsten . . .	1·25–2·00	5·00–6·00	...
Chromium . . .	3·50–4·50	3·50–4·50	3·50–4·50
Vanadium . . .	0·90–1·50	1·40–1·60	1·50–2·25
Molybdenum . .	8·00–9·50	4·00–5·00	7·50–9·50

These steels have been developed in the United States as substitute for the 18/4/1 high-speed steel.

WELDING AND CUTTING

(Continued from pp. 56 A–58 A)

Weldability of Substitute Steels. A. B. Kinzel. (Metal Progress, 1942, vol. 42, July, pp. 71, 136–138). In expansion of an earlier paper on specifying the weldability of steels (*see* Journ. I. and S.I., 1942, No. I, p. 149 A) the author now describes the procedure for ascertaining the suitability of a steel for making a welded assembly to duplicate an assembly originally made of a different steel.

The Effects of Residual Stress and External Restraint on Some Welding Characteristics of SAE *X*-4130 Steel Tubing. G. Sachs and W. E. Davis. (Welding Journal, 1942, vol. 21, Sept. pp. 427-S–433-S). The authors report the results of an investigation of the effects of residual stress and of mechanical restraint while welding on the welding properties of steel tubes. Specimens 2 in. long of $1\frac{3}{4}$-in.-outside-dia. low-alloy steel tube (carbon 0·25–0·35%, chromium 0·80–1·10% and molybdenum 0·15–0·25%) were welded by depositing a single bead on them in the longitudinal direction. Residual stresses before and after welding were determined by slitting specimens and measuring the change in diameter. The stress set up by welding a tube initially free from stress was insignificant and restricted to the vicinity of the weld bead. Welding a tube with an initial residual stress had a stress-relieving effect, and this effect increased with the magnitude of the initial residual stress; the effect was also increased by increases in the welding current and the diameter of the electrode.

Expansion and Contraction. H. H. Griffith. (Welding Journal, 1942, vol. 21, Sept., pp. 591–593). The author points out how the expansion and contraction of metals affect welding operations, and gives practical advice, with some illustrations of examples, on simple methods by which the welder can overcome contraction difficulties. The coefficients of expansion and melting points of aluminium, brass, bronze, copper, stellite, steel and cast iron are given in a table.

Effect of Zinc Chromate Paint on Welding. C. T. Galey. (Welding Journal, 1942, vol. 21, Sept., pp. 434-S–439-S). In order to ascertain whether the presence of a zinc-chromate priming coat on steel affected the soundness and strength of welds made without removing the coating, the authors carried out numerous tensile tests and bend tests on T-pieces of mild and high-tensile steel. No increase in porosity of the weld metal was established by X-ray and metallographic examination, and no detrimental effect on the mechanical properties was observed.

Progress Report on the Use of Flash Welding as a Means of Fabricating Aircraft Structural Parts from X-4130 Steel. R. P. Della-Vedowa. (Welding Journal, 1942, vol. 21, Sept., pp. 421-S–

426-S). The author reports the results of tensile tests on flash-butt welded tubing of chromium-molybdenum steel with different settings of the welding machine. Oscillograms showing the fluctuations in current, voltage and the die travel were obtained, and curves are presented which show the correct settings for the controls of the machine for tubes of various diameters and wall thicknesses. The data obtained proved that good joints of tensile strength equal to that of the tube itself could be consistently obtained, and that the process had several economic advantages.

Welding Chromium Steels. Part II.—Welding Aircraft Cr-Mo Steels. Part III.—Welding Heat-, Wear- and Corrosion-Resistant Chromium Steels. W. Spraragen and H. H. Chiswik. (Welding Journal, 1942, vol. 21, Sept., pp. 389-S–415-S). The authors present a comprehensive review of the literature from July 1937 to December 1941 on the welding of chromium-molybdenum aircraft steels, chromium-silicon-molybdenum heat-resisting steels, 4–6% chromium steels and chromium-nickel stainless steels.

Welding Metallurgy. Volume II. Part V. Fluxes and Slags. O. H. Henry and G. E. Claussen. (Welding Journal, 1941, vol. 20, June, pp. 374–381). Continuation of a series of articles (*see* Journ. I. and S.I., 1941, No. I., p. 178 A). In this part the authors explain why fluxes and slags are necessary in many metallurgical processes, and point out the desirable properties of a flux, in particular those of welding fluxes.

Jigs for Flame Cutting Curved Surfaces. C. N. Holwill and A. N. Kugler. (Welding Journal, 1942, vol. 21, Sept., pp. 609–610). The authors describe and illustrate some ingenious jigs and control devices designed to facilitate the rapid and accurate oxy-acetylene machine cutting of holes and slots in 3-in. and 16-in. steel pipes.

MACHINING

How to Select Efficient Cutting Tools. L. J. St. Clair. (Iron Age, 1942, vol. 150, Oct. 1, pp. 60–67). In the course of long experience with cutting tools the author has found that a tool can be selected for a particular class of work by reference to the three factors hardness at room temperature, red hardness and toughness. Thus, the tensile strength of the material to be cut and the depth of cut to be taken at once limit the choice of a suitable tool steel. The author presents a table in which the common metals and alloys, rubber and plastics are classified according to their tensile strength, and suitable tool steels for making light, medium and heavy cuts are shown opposite each material.

The Grinding of Carbon and High-Speed Steels. A. J. Schroeder. (Metallurgia, 1942, vol. 26, June, pp. 61–63). The author describes equipment for grinding lathe and planing-machine tools, gives a

diagram showing the names of the angles and faces on tools and discusses gauges for testing the correctness of tool angles.

Tipped High Speed Steel Tools Give Improved Performance. L. J. St. Clair. (Iron Age, 1942, vol. 150, Aug. 6, pp. 52–55). The author describes and illustrates some examples of tools tipped with cobalt high-speed steel which have given better performance than tools made of high-speed steel throughout. The tips are brazed to the shanks without the hardness of the tip being affected.

CLEANING AND PICKLING OF METALS

(Continued from pp. 21 A–22 A)

Streamlining Pickle-House Procedure. J. H. Richards, jun. (Wire and Wire Products, 1942, vol. 49, Mar., pp. 453–454, 482, 483). It is common practice in wire-drawing to pass the wire through an alkaline bath and give it a hot-water rinse after pickling in hydrochloric acid. In the present paper the author suggests a procedure which has been successfully used in which the alkaline bath and the rinse are replaced by a single treatment in a bath containing a proprietary compound. The coils are dipped in the bath, and the solution will then dry off in air in less than a minute; a rust-inhibiting coating is left on the wire, which is then ready for coating with lime.

Utilization of Pickle Liquor. F. J. van Antwerpen. (Industrial and Engineering Chemistry, Industrial Edition, 1942, vol. 34, Oct., pp. 1138–1141). The manufacture of "Ferron" building blocks from crushed rock quick-lime and waste pickling liquor has already been described by M. J. Rentschler (*see* Journ. I. and S.I., 1939, No. I., p. 289 A). In the present paper the author describes a more recently developed technique for treating the slurry formed in the early stages of the "Ferron" process in a high-pressure board press to make plaster boards. The properties of these boards and their use for the internal walls of houses are discussed.

Evaluation of a Surface Active Agent for Metal Cleaning. O. M. Morgan and J. G. Lankler. (Industrial and Engineering Chemistry, Industrial Edition, 1942, vol. 34, Oct., pp. 1158–1161). **A Surface Active Agent for Metal Cleaning.** O. M. Morgan and J. G. Lankler. (Metal Industry, 1942, vol. 61, Dec. 4, p. 361). The authors describe tests with alkaline cleaning solutions containing a surface-active agent called "Nacconol NR"; chemically this is an alkyl aryl sodium sulphonate having a long alkyl chain. Specimens of cold-rolled steel sheet, galvanised steel, tinplate, aluminium and brass were dipped in a mineral oil before washing in the test solution, and the effects of hard water, time and temperature on the degree of oil removal were determined by photographing the specimens under

ultra-violet light in which any remaining traces of mineral oil exhibited a bright fluorescence. The addition of the above agent to sodium metasilicate and other solutions enabled the cleaning time, the operating temperature and the concentration of the solution required to produce an absolutely oil-free surface to be considerably reduced.

Removing Heat-Treat Scale. (Steel, 1942, vol. 111, Sept. 28, pp. 64–66). Particulars are given of the "Wheelabrator" shot-blast unit for removing scale from the inside and outside of steel tubes (*see* p. 21 A).

Continuous Feed Dry Process for Removing Scale. (Wire and Wire Products, 1942, vol. 17, Sept., pp. 463–466). A brief description is given of the "Drei-Brite" process of removing scale from hot-rolled rods and strip. The process is a continuous one, in which as many as sixteen rods at a time can be pulled through a scouring chamber $7\frac{1}{2}$ in. wide and 30 ft. long. In this chamber angular steel grit is blown with a turbulent motion, which thoroughly cleans all the surface of the rods or strips in one pass. The grit is automatically returned to the hopper and mixing chamber and is used over again.

COATING OF METALS

(Continued from pp. 23 A–29 A)

Rust-Proofing of Ferrous Metals in Light Engineering Practice. H. Silman. (Sheet Metal Industries, 1942, vol. 16, July, pp. 997–1008; Aug., pp. 1173–1180; Sept., pp. 1344–1351, 1370; Oct., pp. 1531–1536). In this review of modern metal-finishing processes the author deals in succession with electrodeposited and immersion coatings, the conversion of the surface of the metal to one of its more resistant compounds, metal spraying, cementation, cladding, the application of an organic coating (usually but not always a paint or lacquer), and vitreous enamelling.

How to Avoid Use of Critical Materials by Protecting and Finishing Metal Surfaces. C. B. Young. (Steel, 1942, vol. 111, Oct. 19, pp. 64–65, 84–91). The author reviews methods of producing protective surfaces on metals using heat and chemical treatments only. The temperatures of heat treatment to produce blue oxide coatings on steel are given. Black surfaces can be produced by heating within the 1000–1200° F. range and quenching in oil. The nitre bath consists of a mixture of equal parts of sodium and potassium nitrate with some manganese dioxide; this is heated to about 900° F., and produces a blue oxide film. Some details of the following proprietary processes are given: "Black Magic," "Ebonol," "Houghto-Black," "Jetal," "Pentrate," "Irco-Izing" and "W.O. No. 1."

The Adherence of Thick Silver Plate on Steel. II. H. L. Crosby and L. I. Gilbertson. (Electrochemical Society, Oct., 1942, Preprint 82–20). In an earlier paper (*see* Journ. I. and S.I., 1939, No. I., p. 36 A) one of the authors (L. I. Gilbertson) showed that a preliminary silver strike is essential to good adherence of silver plate on steel. The purpose of the work described in the present paper was to study the structure of electrodeposited silver, particularly with regard to the effect of striking. Microscopic examination indicated that the adherence of silver on steel is dependent on factors other than interlocking. The authors suggest that the strike produces crystal nuclei at the edges of ferrite crystals and that the columnar, usually twinned, silver crystals formed on electrodeposition grow from these nuclei. The most important factor controlling the adherence of the silver plate on steel is, therefore, the intra-atomic bond between closely associated crystals of ferrite and silver, which seems to be enhanced by the use of a silver strike before plating.

The Structure of Brush-Plated Silver. H. L. Crosby and L. I. Gilbertson. (Electrochemical Society, Oct. 1942, Preprint 82–21). The authors studied the nature of silver electrodeposited by means of a brush electrode on hot-rolled mild steel. They found by microscopic examination that the deposits are of lamellar structure and suggest that this is the cause of their low porosity and, consequently, their great protective value.

The Effect of Copper on Hot-Dip Zinc Coatings. W. G. Imhoff. (Wire and Wire Products, 1942, vol. 17, Aug., pp. 391–396, 422, 423). The author reviews the available information on the effect of copper, whether deliberately added or originating from the ores used in zinc manufacture, on the quality and corrosion resistance of zinc coatings. The subject is dealt with under the headings : (*a*) Copper in zinc ; (*b*) copper in the galvanising bath ; (*c*) copper in galvanising pot material ; (*d*) copper in zinc coatings ; (*e*) effect of copper on the corrosion of zinc coatings ; (*f*) copper in the dross and skimmings. Standard prime slab zinc as supplied to United States galvanisers does not contain copper, and remelted zinc may contain only up to 1% of copper. It is not practicable to galvanise copper articles because copper is readily attacked and dissolved by molten zinc at galvanising temperatures. In the author's opinion it is not harmful to have traces of copper in the steel of which the galvanising pot is made but the amount should certainly be less than 0·5%. Almost as great an improvement in corrosion resistance will be obtained by small additions of copper in the zinc bath as that obtained by adding copper to steel. Brauer and Peirce state that about 0·5% of copper in a zinc coating strongly retards oxidation and any amount up to 5% is beneficial. The author has found however that additions of more than about 0·2% of copper to the zinc in a hot-dip bath caused a red copper-oxide smear to appear on the zinc coating.

Electro-Tinplate. W. E. Hoare. (Metallurgia, 1942, vol. 26, Aug., pp. 137–139; Oct., pp. 219–221). After discussing the tin shortage and tin requirements of the United States, the author points out that one method of conserving tin is the increased use of the electrolytic tinning process with its ability to deposit exceedingly thin coatings. The alkaline and acid baths for electrolytic tinning are then described. The major advantage of the former is that it has an intrinsic cleaning action on work placed in it, so that a high degree of cleanliness of the steel surface is not necessary. Data from previously published descriptions of acid and alkaline electrolytic tinning plants are quoted. Good progress is being made in the United States with the process of "flow brightening." A surface with a higher polish, good lacquering capacity and increased corrosion resistance is obtained by flow brightening, which involves heating the tinned strip to just above the melting point of the coating for a comparatively short time. One method is to pass the strip through a double reservoir of oil; the two compartments of the tank are connected by a sloping duct, through which the strip passes from the hot oil section to the cold oil section; this ensures rapid freezing of the fused coating.

Electro-Tinning. S. Baier. (Monthly Review of the American Electroplaters' Society, 1942, vol. 29, Sept., pp. 735–749). The author gives a comprehensive account of electrolytic methods of coating steel with tin, including some recommended analytical methods of controlling the solutions.

Tin Plating from the Potassium Stannate Bath. M. M. Sternfels and F. A. Lowenheim. (Electrochemical Society, Oct., 1942, Preprint 82–24). The authors investigated the properties of potassium-stannate/potassium-hydroxide plating baths with a view to retaining the advantages of the usual alkaline bath while extending its useful range of current densities and concentrations. They observed the following effects when substituting potassium for sodium in stoichiometrically equivalent quantities: The conductivity was increased by about 25%, and the cathode efficiency was notably raised, whereas the anode efficiency was not greatly affected. The higher solubility of potassium stannate permits the baths to be operated at temperatures unattainable with the corresponding sodium salt baths, so that higher conductivities and electrode efficiencies can be achieved. The deposits obtained compare favourably with those from sodium stannate baths. In conclusion the authors indicate possible fields of application of the potassium-stannate tinning bath, referring especially to the electro-tinning of steel strip.

Modern Wire Enamelling Equipment. O. S. Haskell. (Wire and Wire Products, 1942, vol. 17, Sept., pp. 447–450, 476, 477). The author describes and illustrates machinery and equipment at the wire department of the General Electric Co., Schenectady, for the enamelling of wire from 8 gauge down to sizes smaller than 40 gauge.

Bonderised and Lacquered Steel Sheet. L. Schuster. (Iron and Coal Trades Review, 1942, vol. 145, Nov. 20, pp. 1169–1171). An abridged English translation is presented of the author's recent review of German methods of bonderising and lacquering food cans. The corrosion resistance and physical properties of the cans are dealt with. The original paper appeared in Stahl und Eisen, 1942, vol. 62, Aug. 13, pp. 685–694 (*see* p. 34 A).

Temporary Protective Coating. (Steel, 1942, vol. 111, Oct. 5, p. 126). Some particulars are given of "Carbozite," a black liquid used for the temporary protection of steel surfaces during transport and storage. This fluid dries rapidly to a hard gloss, which is resistant to acids, alkalis, moisture, sea air and temperatures up to about 400° F. Carbozite is made from a bituminous ore occurring in the Western United States.

PROPERTIES AND TESTS

(Continued from pp. 58 A–64 A)

Influence of Strain Rate on Strength and Type of Failure of Carbon-Molybdenum Steel at 850, 1000 and 1100 Degrees Fahr. R. F. Miller, G. V. Smith and G. L. Kehl. (American Society for Metals, Oct., 1942, Preprint No. 24). The authors describe a tensile testing machine with which specimens can be tested to fracture at a selected uniform rate of strain at any desired temperature, and report the results of tests on pearlitic and spheroidised carbon-molybdenum steel. As the strain rate was decreased, the tensile strength decreased, the elongation first increased and then decreased, and the mode of fracture changed from intragranular to intergranular. It was concluded that intergranular failure is normal in metals strained slowly at elevated temperatures, and that this does not necessarily indicate deterioration of the material or lack of plasticity preceding fracture.

Stress-Strain Measurements in the Drawing of Cylindrical Cups. E. L. Bartholomew, jun. (American Society for Metals, Oct., 1942, Preprint No. 9). The author reports on the results of stress-strain measurements on S.A.E. 1010 deep-drawing steel sheet and on several non-ferrous alloys during drawing into cylindrical cups from blanks of various diameters. He represents the data obtained in the form of s–q' curves, as suggested in a paper by MacGregor (*see* Journ. I. and S.I., 1940, No. II., p. 153 A). He points out, however, that it is not necessary to trace these curves in practice, but that it is sufficient to measure the elongation at maximum tensile load prior to necking down. The magnitude of the actual stresses in tensile tests is correlated with the tensile stresses in the cup walls of blanks of maximum diameter, *i.e.*, the diameter re-

presenting the limit of drawability of any metal for given conditions. The tensile test data can thus be used to determine this diameter, and they can, in fact, be considered to be an index of the drawability of a metal. The maximum blank diameter can be determined with an accuracy of $\pm$ 0·05 in.

The Yield Point in Steel. C. A. Edwards, D. L. Phillips and Y. H. Liu. (Iron and Steel Institute, 1943, this Journal, Section I.). Some of the explanations which have been offered to account for the phenomena of the " upper " and " lower " yield points in mild steel during tensile testing have been examined. It is confirmed that the behaviour of mild steel in this respect is an intrinsic property of the material, and is not due to the inertia of the testing equipment. It is also confirmed that the value of the yield stress is affected by the rate of loading. No support has been obtained for the hypothesis that the yield point is due to some kind of retardation in the ability of the metal to react to increasing stresses, if insufficient time is given for plastic deformation to be initiated, and that no yield point would be shown in mild steel if extremely slow rates of loading were used. The yield point in mild steel can no longer be attributed to the body-centred cubic lattice structure, since similar kinds of yield points have been found with alloys in which the solvent metals possess the face-centred structure. The authors believe that when a yield point is obtained, it is associated with the presence in the metal of an element which is more soluble at high than at low temperatures, and with a treatment which causes this element to be precipitated on certain planes of slip within the crystals.

Notched Bar Tensile Tests on Heat Treated Low Alloy Steels. G. Sachs and J. D. Lubahn. (American Society for Metals, Oct., 1942, Preprint No. 8). The authors carried out tensile tests on notched bars of low-alloy steels containing carbon 0·4% and nickel, nickel plus chromium, chromium plus molybdenum and chromium steel, and 1·8% manganese steel which had been tempered at various temperatures. They found that the ductility of the steel was considerably reduced in the notched section. The strength of such soft steels was increased by a percentage which was approximately equal to the percentage reduction of the cross-sectional area due to the notch. A shallow notch did not seriously affect the notch strength or the notch ductility of stronger steels. The ductility of deeply notched specimens, however, was nearly zero and their strength greatly reduced. This condition prevailed for steels with an ultimate strength of between 220,000 and 280,000 lb. per sq. in., although the ductility given by ordinary tensile tests remained almost as high in this strength range as for softer steels. The embrittling effect of overheating and large size of the specimen section, which does not play any rôle in ordinary tensile tests, affected the results of notched-bar tensile tests. The authors' findings lead to the conclusion that ordinary tensile tests should be replaced by notched-bar tensile tests if the

purpose is to establish the suitability of a steel for commercial applications involving shoulders, key-ways and other irregularities in shape that produce an effect similar to that of a deep notch. The authors correlate their test results with the shape of the stress-strain curve for the notched section, and with previous conceptions of the laws of plastic flow and stress distribution in a notched section.

Effects of Notching on Strained Metals. G. Sachs and J. D. Lubahn. (Iron Age, 1942, vol. 150, Oct. 8, pp. 31–38; Oct. 15, pp. 48–52). The authors review the literature on the effect of notches on the tensile strength of metals and on the distribution of stress in tensile specimens.

The Tensile-Impact Resistance of Carbon-Molybdenum Welds at Elevated Temperatures. O. H. Henry and M. A. Cordovi. (Welding Journal, 1942, vol. 21, Sept., pp. 416-S–420-S). The authors report the results of hardness, tensile and impact tests at temperatures of 70°, 550°, 770°, 900° and 1000° F. on specimens cut from welded joints in tubing in which a tube of 2·25%-chromium 1%-molybdenum steel was welded to a 1%-molybdenum steel tube using molybdenum steel electrodes. A pendulum-type Tinius-Olsen impact machine adapted for tensile-impact testing was used. The tensile-impact strength was highest at room temperature; it decreased slightly in the "blue heat" range and was lowest at 950° F. The elongation dropped to about 55% of its original value in the 700–750° F. range and then increased; at 1000° F. it was only 3% smaller than at room temperature.

The Effect of Moderate Cold Rolling on the Hardness of the Surface Layer of 0·34 Per Cent. Carbon Steel Plates. H. K. Herschman. (American Society for Metals, Oct., 1942, Preprint No. 34). The author investigated the effect of cold-rolling on the surface hardness of annealed 0·34%-carbon steel plate the surface of which was finished prior to cold-rolling by three different methods—viz., grinding, buffing and metallographic polishing. The experimental data showed that the Knoop hardness number for the surface layer was lower after cold-rolling reductions of 1% and 2% than it was prior to rolling. The most significant decreases in hardness appeared to occur in a layer less than 0·0003 in. thick.

The Resin Method of Indicating Yield. J. S. Blair. (Engineer, 1942, vol. 174, Dec. 4, pp. 455–456). In the testing of steel structures, tubular assemblies and even complex structures up to 100 ft. span, the method of coating with resin to reveal the position of localised stresses, Lüders lines and to make stress analyses has been used with success, but the success depends largely on the correct application of the resin. The author describes methods of applying the resin and discusses some results obtained. Any coating such as paint must be removed first. A small test-piece should be dipped into a bath of molten resin at 140° C. and left in it long enough for the whole of the piece to reach the temperature of the

bath. Larger test-pieces may be coated partially or wholly by heating the surface with a blow-lamp and coating them piecemeal. The temperature is very important, for if it is too high, the resin will either burn or run off and leave practically no coating; if, on the other hand, it is too low, the resin will stick and not wet the surface properly.

Fatigue Strength of Normalized and Tempered *Versus* As-Forged Full Size Railroad Car Axles. O. J. Horger and T. V. Buckwalter. (American Society for Metals, Oct., 1942, Preprint No. 10) The authors report on rotating-cantilever fatigue tests made on forty-eight full-size railway car axles to determine the fatigue strength of the axle wheel seat on which the wheel is pressed. Plain carbon steels with 0·39–0·53% of carbon were examined in the as-forged as well as in the normalised and tempered condition. It was found that the fatigue resistance in the wheel seat of as-forged axles is greater by one-third than that of normalised and tempered axles of practically the same carbon content. Also in two groups of as-forged axles, the resistance to the initiation of fatigue cracks was greater by one-third in the group including the steels with about 0·5% of carbon than it was in that including the steels with about 0·4% of carbon.

File-Hardness Testing. J. H. Hruska. (Iron Age, 1942, vol. 150, Sept. 24, pp. 35–39). The author describes methods of testing the hardness of files, especially that of small square test-files which are used for scratch-testing metal surfaces.

The End-Quench Test: Reproducibility. M. Hill. (American Society for Metals, Oct., 1942, Preprint No. 11). The author reports on an investigation of the reproducibility of the results obtained in the S.A.E. standard end-quench hardenability test. Cooling curves were plotted from data obtained with thermocouples in holes in the specimen at different distances from the quenched end. It was found that the transformations could be predicted from the cooling curve and the S-curve for the particular steel. The only testing condition which must be rigorously controlled is that there must be no scale on the quenched end of the specimen.

The End-Quench Test: Hardenability of Aircraft Steels and its Representation. M. Hill. (American Society for Metals, Oct., 1942, Preprint No. 12). The author presents and discusses data on the hardenability of a number of United States low-alloy steels for aircraft construction. Considerable variations within single heats were found by the S.A.E. standard end-quench test. To facilitate the comparison of numbers of curves representing the relation between the Rockwell C hardness and the distance from the quenched end, the author developed a system of representing each curve by three straight lines, for in all cases three (or less) straight lines could be drawn such that the distance between the curve and one of the lines was never greater than 3 points. The position of these straight lines was denoted by two numbers representing a starting point

and the slope. The usefulness of this system is demonstrated by examples.

Hardenability Control of a 1 Per Cent Carbon Steel. G. R. Barrow and G. Soler. (American Society for Metals, Oct., 1942, Preprint No. 13). The authors describe how a method of predicting the hardenability of a 1% carbon steel was developed by using data collected for more than 600 heats of the steel which were made in an electric furnace by the double-slag process. The Jominy and S.A.E. end-quench hardenability tests were insufficiently sensitive for this shallow-hardening steel, and a special test was used. Specimens 1 in. in dia. were normalised for 1 hr. at 870° C. and quenched from 775° C. in a brine spray of 1·070–1·074 sp. gr.; the brine temperature was kept at 100° F. and a constant pressure was maintained. The specimens were then sectioned and etched, and the depth of the hardened zone was measured. The system evolved was that the steel was classified into one of five degrees of hardenability which depended on the sum of the manganese, silicon, chromium and nickel contents.

Some Aspects of Strain Hardenability of Austenitic Manganese Steel. D. Niconoff. (American Society for Metals, Oct., 1942, Preprint No. 32). The author reports on a further stage of his investigation of the strain-hardenability of a 12·5% manganese steel (*see* Journ. I. and S.I., 1941, No. I, p. 106 A). It was desired to determine whether the capacity to harden when cold-worked was affected by the extent of the decomposition of the austenite. It was found that the maximum strain-hardness attainable in an austenite manganese steel of a given composition was practically the same, irrespective of variation in structure and initial hardness induced by different heat treatments.

The Effect of Hardness on the Machinability of Six Alloy Steels. O. W. Boston and L. V. Colwell. (American Society for Metals, Oct., 1942, Preprint No. 4). The authors studied the effect of the hardness of steel on its machinability by means of a series of lathe-tool life tests on six commercial alloy steels in the quenched and tempered state. The material and shape of the cutting tool, the size of the cut and the cutting fluid represented commercial practice. The steels gave a wide range of machinability ratings, particularly in the high hardness range. There appeared to be a direct relationship between the hardenability and the machinability of the harder steels, *i.e.*, exceeding 400 Brinell; with these one of the conditions for good machinability was that the steels must possess a high degree of hardenability or uniform hardness penetration.

Magnetic Materials. A. J. Corson. (General Electric Review, 1942, vol. 45, Oct., pp. 573–575). The author discusses how the application of modern magnetic alloys has improved the design and performance of A.C. and D.C. electrical indicating instruments.

The Detection of Cracks in Castings by an Electrical Method. B. M. Thornton. (Foundry Trade Journal, 1942, vol. 68, Nov. 26,

pp. 277–278). In an earlier paper a description was given of an instrument for testing the wall thickness of castings from one side only (*see* Journ. I. and S.I., 1942, No. I., p. 37 A). In this paper some experiments with the same type of instrument to detect cracks in castings are described. The method is essentially that of comparing the electrical resistance of the metal wall under test with that of a similarly shaped wall of the same material which is known to be free from flaws. The tests described detected cracks in pieces of $\frac{3}{4}$-in. cast-iron plate.

The Fluorescent Penetrant Method of Detecting Discontinuities. T. de Forest. (American Society for Metals, Oct., 1942, Preprint No. 19). The author describes a new method of testing metals to discover surface defects. The part to be examined is immersed in or coated with a thin penetrative oil carrying an oil-soluble fluorescent agent; the excess of the fluorescent liquid is washed off with water, the part is then dried and coated with a very fine powder, which draws the liquid back out of any cracks or defects; finally, an examination is made under ultra-violet light, when the position of cracks is revealed by the white fluorescence of the liquid absorbed by the powder.

True Stress-Strain Relations at High Temperatures by the Two-Load Method. C. W. MacGregor and L. E. Welch. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1507: Metals Technology, 1942, vol. 9, Sept.). A method of obtaining true stress-strain data in tensile tests by observation of the maximum load and the load at fracture has already been described by C. W. MacGregor (*see* Journ. I. and S.I., 1940, No. I., p. 295 A). The authors now report on an investigation of the application of this method to short-time tensile tests at high temperature. The results of tests on two carbon steels, one low-alloy steel, three high-alloy steels, brass and Monel metal are presented. The conclusions reached were: (1) The two-load method can be used in the short-time high-temperature test provided appreciable creep does not occur during the test; (2) The true stress-strain curves are linear from the point of maximum load to that of incipient fracture; (3) the effect of heat on the true stress at the maximum load and on the average true stress at fracture was different for most of the materials tested; (4) the ductility of metals at high temperature can be pictured by comparing the true uniform strain with the true local necking strain; (5) the effect of heat upon the two strains referred to in (4) was different; and (6) heat affected the true strain at fracture and the true local necking strain in a similar manner.

"Fish-Eyes" in Steel Welds Caused by Hydrogen. C. A. Zapffe. (Metal Progress, 1942, vol. 41, Aug., pp. 201–206). The author discusses the pressure which can be developed by hydrogen in steel. He presents curves showing the changes of pressure with temperature as calculated for iron containing 0·0025%, 0·0005% and 0·0002% by

weight of hydrogen, and explains why the pressure increases one hundred times when the solubility in iron is decreased to one-tenth by lowering the temperature. In experiments with steel, hydrogen pressures up to about 5000 lb. per sq. in. have been measured. It is generally agreed that iron at room temperature cannot hold more than 0·00001% by weight of hydrogen in true solution under one atmosphere of hydrogen, but quantities 20,000 times greater than this have frequently been expelled from specimens in experiments. It therefore appears that the major portion of the gas occluded at ordinary temperatures must be "extra-lattice." If nickel or palladium is loaded with hydrogen, coated with a transparent liquid and deformed, bubbles of gas visibly escape from the deformation lines; the same is true for iron. The author considers that the popular conception of slip planes and slip lines (the latter appearing as a relief effect caused by homogeneous shear) must be amended. The slip plane is more likely an actual disjunction of crystals in an otherwise heterogeneous lattice and astonishingly large quantities of hydrogen collect there at very high pressure, so high that it may exceed the elastic limit of the steel. When the pressure is so high the hydrogen may "spring open" the slip plane and lock the surrounding lattice against further motion, thus causing brittleness. The brilliant crystalline zone surrounding a hydrogen blow-hole (hence the term "fish-eye") comprises the flat crystallographic surfaces of large groups of blocks of crystals which have been immobilised and partly separated by the pressure of the occluded hydrogen.

Relative Effect of Elements on Alloy Steels. J. Mitchell. (Metal Progress, 1942, vol. 42, July, pp. 53–60). The author explains a system of allotting numbers and letters to elements in low-alloy steels in order to provide a simple means of showing the effect of the element on the properties of steel. The rating numbers vary from zero to +10 when the effect is favourable, and from zero to −10 when the effect is detrimental; the suffix letter "P" indicates that the effect is in proportion to the amount of the element; the letter "S" indicates that small amounts have relatively greater effect than large additions, and the letter "L" that large amounts are most effective. The system applies to the following elements in low-alloy steels: carbon, manganese, phosphorus, sulphur, silicon, chromium, nickel, molybdenum, vanadium and copper.

Investigations on the Influence of Phosphorus, Sulphur, Manganese, Vanadium and Tin on the Hardening Properties of Carbon Steel with 0·75–1·00% C. S. von Hofsten. (Jernkontorets Annaler, 1942, vol. 126, No. 1, pp. 1–33; No. 2, pp. 49–70). (In Swedish). In 1935 Jernkontoret sponsored a series of investigations of the hardening properties of steel; it was later found necessary to restrict the scope of the work so as to make known any results of special interest within a reasonable time. An account of the work on the effects of phosphorus, sulphur, manganese, vanadium and tin on the hardenability of steel is now published under the general editorship of

S. von Hofsten. After an introductory statement by him the following reports are presented :

(1) The Effect of Phosphorus on the Hardening Properties of Carbon Steel with about 0·90% of Carbon. This consists of a review by E. Öhman of investigations carried out by B. D. Enlund, S. von Hofsten, H. Kjerman, G. Malmberg and A. Wahlsteen, as well as reports from Hagfors Jernverk and Metallografiska Institutet.

(2) The Effect of Sulphur on the Hardening Properties of Carbon Steel with 0·75–1·00% of Carbon, by S. von Hofsten.

(3) The Effect of Manganese on the Hardening Properties of Carbon Steel with 0·50–1·00% of Carbon, comprising :

A Summary, by S. von Hoftsen.

The Effect of Manganese on Basic High-Frequency Furnace Steel, by G. Malmberg.

The Effect of Manganese on Acid High-Frequency Furnace Steel, by B. D. Enlund.

The Effect of Manganese on Acid High-Frequency Furnace Steel, by S. von Hofsten.

(4) The Effect of Vanadium on the Hardening Properties of Carbon Steel with 0·9% of Carbon, comprising :

A Summary, by S. von Hofsten.

The Effect of Vanadium on Basic Open-Hearth Steel, by B. D. Enlund.

The Effect of Vanadium on Acid Open-Hearth Steel, by H. Kjerrman.

The Effect of Vanadium on Basic High-Frequency Furnace Steel, by G. Malmberg.

(5) The Effect of Tin on the Hardening Properties of Acid High-Frequency Furnace Steel, by A. Wahlsteen.

The effect of the above alloying elements was studied by making impact tests by the Jernkontoret Standard Method, using 22-mm. dia. specimens with a machined V-notch 0·4 mm. deep and 1·2 mm. wide, and as a basis of comparison an " impact fracture index " (*härdbrottssumma*) was established. This index, which is referred to as the " *Hbs.*" number, is the total of six impact-test results for each steel carried out on specimens quenched from 770°, 800°, 830°, 860°, 890° and 920° C., respectively. The grain size of the fractured surfaces was also studied.

(1) *Phosphorus.*—In general, increasing the phosphorus caused a steady reduction in the *Hbs.* index ; in some cases the relationship was linear. The magnitude of the effect differed greatly with different steels, and it appears that the influence of phosphorus can easily be dominated by other changes in the properties of the steel. Phosphorus had the greatest effect on basic H.F. furnace steel and on acid open-hearth steel. The depth of hardness always increased with increasing phosphorus and so did the tendency to hardness cracks.

(2) *Sulphur.*—The *Hbs.* index rose rapidly with increasing sulphur, the rise being greatest with the first increase in sulphur and then becoming less marked with further additions of sulphur. The effect of sulphur was the same whether aluminium was added or not. The hardness depth markedly decreased as the sulphur content increased.

(3) *Manganese.*—In steels without any aluminium addition, increasing the manganese from a very small amount to 0·5-1·0% caused a steady decrease in the *Hbs.* index; above this amount further increases had practically no further effect. By adding a fair amount of aluminium the grain-enlargement effect of manganese was completely suppressed. Thus, increasing the manganese either left the *Hbs.* index unaltered or caused the reduction in the impact values at the higher hardening temperatures to be not so great for higher manganese contents as for the normal low content. The hardness depth of steel with no aluminium addition increased markedly with increasing manganese. It was found possible by a combination of high manganese and aluminium additions to produce a deep-hardening steel with a fracture finer-grained than that of shallow-hardening steel with normal manganese contents.

(4) *Vanadium.*—A well-deoxidised H.F. furnace steel high in silicon made with a reducing slag was found to be most sensitive to vanadium additions, whilst a basic open-earth steel required much more vanadium to produce the same fine-grained fracture; the behaviour of acid open-hearth steel was between these two extremes. The hardness depth increased steadily with increasing vanadium when hardening from the same temperature. There was no measurable change in the surface hardness of steels with different vanadium contents up to 1%.

(5) *Tin.*—Successive increases in tin from 0·002% to 0·39% had practically no effect on the *Hbs.* index; but this could be raised by additions of aluminium even with tin present within the above limits. With certain reservations it can be said that increasing the tin causes the hardness depth to be irregular, but with aluminium also present the hardness depth is more uniform.

Effect of Elements in Solid Solution on Hardness and Response to Heat Treatment of Iron Binary Alloys. C. R. Austin. (American Society for Metals, Oct., 1942, Preprint No. 1). The author studied the effects of various heat treatments on the hardness and structure of electrolytic iron alloyed with one of the following elements in quantities between 0·5 and 5%: chromium, cobalt, nickel, manganese, molybdenum and silicon. His observations led to the following conclusions: (1) A distortion of the lattice of ferritic iron, either by heating to an elevated temperature followed by rapid cooling or by adding certain alloying elements forming solid solutions, results in an increase in hardness. (2) The greater the difference in atomic radius between the added element and α-iron, the greater is the hardening effect. (3) The addition of an element possessing a type

of crystal structure different from that of iron results in greater solid-solution hardening. (4) Elements, the solubility of which in α-iron is low, have a greater hardening effect than those with high solubility.

Third Element Effects on Hardenability of a Pure Hypereutectoid Iron-Carbon Alloy. C. R. Austin, W. G. Van Note and T. A. Prater. (American Society for Metals, Oct., 1942, Preprint No. 2). The authors studied the effect of the austenitic grain size and of additions of up to 0·5% of nickel, copper, silicon, manganese, aluminium and chromium on the hardenability of a pure hypereutectoid steel. The hardenability was determined by the Jominy end-quench test, and in a preliminary study the effects of various factors on the results of this test were established. The investigation led to the conclusion that, expressed in terms of the critical cooling velocity, the hardenability increases linearly with the austenite grain size, whereas no linear relationship seems to exist between the hardenability and the amount of alloying element added.

NE (National Emergency) Alloy Steel Data. C. M. Parker. (Steel, 1942, vol. 111, Oct. 19, pp. 66–76, 95–97). The author discusses the presentation of data on the properties of the National Emergency steels and explains how limited data can be used to decide whether one of the new steels would be suitable in all respects for a particular application.

Appraisal of NE Steels in Terms of Old Types. F. B. Foley. (Metal Progress, 1942, vol. 42, Sept., pp. 365–367). The author explains how the hardenability of one of the National Emergency steels can be related to that of the established S.A.E. steels from Jominy end-quench test curves for the latter steels and one, or at the most two, hardness determinations on the new N.E. steel.

Suitability of Alternate Steels for Aircraft Parts. A. C. Willis and M. Hill. (Metal Progress, 1942, vol. 42, Sept., pp. 370–375). The authors present test data accumulated at the Materiel Center of the United States Air Forces on new low-alloy steels which comply with the Aeronautical Material Specifications.

Low-Alloy Steels. (Automobile Engineer, 1942, vol. 32, Dec., pp. 543–545). With a view to indicating the probable increased application of low-alloy steels after the war a survey is presented of the characteristics, in particular the weldability, of steels alloyed with one or more of the following elements : manganese, silicon, nickel, chromium and molybdenum.

High Manganese Austenitic Steels. R. Franks, W. O. Binder and C. M. Brown. (Iron Age, 1942, vol. 150, Oct. 1, pp. 51–57). The authors report the results of tests on three series of high-manganese austenitic steels. These series consisted of : (1) Steel containing 16% of manganese, up to 2% of nickel and/or up to 1% of copper ; (2) steel similar to (1) with about 3% of chromium ; and (3) 16/12 manganese-chromium steel. The test data reveal that steels (1)

and (2) with low carbon contents can be cold-rolled to a high tensile strength without serious loss of ductility. Steel (3) has similar properties and is also very resistant to corrosion.

" Amola " Steels (Carbon-Molybdenum). F. E. McCleary. (Metal Progress, 1942, vol. 42, Sept., pp. 386–388). The author presents data on the properties of " Amola " steels which were developed by the Chrysler Corporation as substitutes for chromium-vanadium steels. They contain manganese 0·70–0·90%, silicon 0·20–0·30% and molybdenum 0·15–0·25%. They can be supplied in a wide range of carbon contents (0·20–0·70%). The hardenability is controlled by the amount and balance of the molybdenum and manganese.

Effects of Tin on the Properties of Plain Carbon Steel. J. W. Halley. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1513 : Metals Technology, 1942, vol. 9, Sept.). The inclusion of increasing quantities of tinned steel in scrap charged in the steel furnaces makes the question of the effect of tin on the properties of steel of great importance in wartime. In this paper the author reports the results of tests to ascertain the effects of increasing amounts of tin in low-carbon rimming steel, medium-carbon forging steel and rail steel. In general, the addition of tin slightly increases the tensile and yield strengths and slightly reduces the elongation and Charpy impact test values. Tin has an effect similar to that of phosphorus; in structural steels an additional 0·01% of phosphorus increases the tensile strength by 1000 lb. per sq. in. and the same increase in strength would be obtained by a addition of 0·05% of tin.

Tests in the Development of a Tungsten-Free High-Speed Steel Containing 12% of Chromium. W. N. Berchin. (Awiazionnaja Promyschlennosti, 1941, No. 4, pp. 7–13 : Stahl und Eisen, 1942, vol. 62, Sept. 10, pp. 782–783). The author reports the results of hardness and machinability tests on the Russian steel *Ch* 12*M* containing carbon 1·46%, chromium 11·7%, molybdenum 0·7%, nickel 0·3% and vanadium 0·2%. The heat-treatment temperatures were found to be very critical and in certain classes of machining tests the steel was found equal to 18/4/1 (tungsten-chromium-vanadium) high-speed steel.

Conserves Alloys in Bolting Materials. (Steel, 1942, vol. 111, Nov. 2, pp. 92–97). Particulars are given of some new specifications, drawn up by an American firm of oil engineers, for steel for bolts and nuts to be used on oil-refinery pipe lines and pressure vessels. These steels are, in general, of the high-carbon type with reduced amounts of chromium and/or nickel or no alloying elements at all.

Bursting Tests on Notched Alloy Steel Tubing. G. Sachs and J. D. Lubahn. (American Society for Metals, Oct., 1942, Preprint No. 7). The authors report on bursting tests on notched and unnotched tube specimens (length 4·25 in., outside dia. 1·65 in., inside dia. 1·50 in.) of hardened S.A.E. 2340 steel, heat-treated at

790° C. A state of multi-axial stress was produced in the specimens by subjecting them simultaneously to longitudinal tension and to internal pressure, creating circumferential tension. A specially designed apparatus was used for this purpose, which is illustrated and described in some detail. The investigation led to the following conclusions : (1) Tubes subjected simultaneously to circumferential and longitudinal tension show slightly higher tensile strength and much lower ductility values in the circumferential direction than rods tested in tension. (2) A sharp longitudinal notch on the outside surface of a tube is the most severe embrittling agent known so far, steels with a strength level as low as 150,000 lb. per sq. in. having a notch strength below that of unnotched tubes. (3) A single notch did not have the strength-increasing effect expected, whereas a double notch (on both the inside and outside surface) did produce such an effect. The increased lateral stress responsible for this did not cause any greater embrittlement than a single notch, however. (4) No effect of fibre direction was observed in tests on notched tubes machined from rod.

The Interpretation of Steel Specifications. E. Gregory. (Engineering Inspection, 1942, Autumn Issue, pp. 4–7). The author discusses the provisions of some steel specifications, in particular British Standard Specifications 970 and 971, and stresses that they are intended, at the most, to serve as a guide to acceptance or rejection of material and that the conditions laid down must be intelligently interpreted.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 64 A–66 A)

A Method of Sampling for Metallurgical Test-Pieces. C. T. Eakin. (Metal Progress, 1942, vol. 41, Aug., pp. 207–208). The author describes a simple cutting tool for taking metallographic specimens from castings and parts. The drill consists essentially of a tubular member with cutting teeth at one end ; there is a plug at the other end, and a centering device consisting of a pin and spring is fitted in the tube. Before using the tool, a $\frac{1}{16}$-in. pilot hole $\frac{1}{8}$ in. deep is drilled in the casting at the desired spot. The tool is then inserted in a portable power- or hand-driven drill ; the projecting centering pin is inserted in the pilot hole and drilling started until the tool is sufficiently deep to be self-guiding ; the centering pin is then removed and the drilling continued to the required depth. The core is broken off at the bottom by flexing it and this is ground and polished to form the specimen.

Simplified Electro-Polishing of Steel Specimens. R. W. Parcel. (Metal Progress, 1942, vol. 41, Aug., pp. 209–212). The author

describes an electrolytic polishing technique developed by the Denver & Rio Grande Western Railway for polishing specimens of steel and aluminium. The method is a modification of one previously described (*see* "An Improved Cell for Electrolytic Polishing," Journ. I. and S.I., 1942, No. I., p. 118 A), and the electrolyte is made up of perchloric acid, water, ethyl alcohol and ether. A special small cell is also described; this can be clamped on to heavy parts which cannot always be taken to a laboratory.

Anodic Treatment of Plain Carbon Steels. R. L. Imboden and R. S. Sibley. (Electrochemical Society, Oct., 1942, Preprint 82–18). The authors subjected low-carbon steel specimens to anodic treatment for polishing as well as etching. The following three baths proved particularly satisfactory for polishing and, without the organic additions and at slightly lower current densities, for etching: (1) A mixture of 40% of sulphuric acid, 46% of phosphoric acid, 4% of dextrose and 10% of water used at 28–40° C. with a current density of 1·5–4·5 amp. per sq. in. (2) A mixture of 15% of sulphuric acid, 65% of phosphoric acid, 5% of chromic acid and 15% of water used at 42–55° C. with a c.d. of 3–7 amp. per sq. in. (3) A mixture of 765 c.c. of acetic anhydride, 185 c.c. of perchloric acid and 50 c.c. of water used below 30° C. and with a c.d. of 0·25–0·8 amp. per sq. in. The times required for polishing are 5–10 min. with the first and third baths and 3–5 min. with the second one. The authors point out that, by assuming the effect of the anodic treatment to be due to the formation of an insulating film on the specimen surface, the following phenomena can be explained: (*a*) The preferential removal of scratch ridges, (*b*) the longer time required with vigorous stirring, (*c*) the formation of undulations on the surface, and (*d*) pitting around surface inclusions. In conclusion, the advantages of the electropolishing of plain carbon steel specimens are summarised, and the apparatus used for the authors' experiments is described. Micrographs of several of the treated specimens are presented.

The Metallography of Galvanized Sheet Steel Using a Specially Prepared Polishing Medium with Controlled *p*H. D. H. Rowland and O. E. Romig. (American Society for Metals, Oct., 1942, Preprint No. 6). The authors discuss the preparation of cross-sections of galvanised sheet steel for micrographic examination at magnifications of 500–1000 diameters, and give details regarding a special alumina polishing suspension in water with controlled *p*H value, for which alumina prepared by roasting of aluminium sulphate and extracting undecomposed sulphate with hot water is used.

On the Location of Flaws by Stereo-Radiography. J. Rigbey. (American Society for Metals, Oct., 1942, Preprint No. 18). The author describes a technique for obtaining stereoscopic radiographs of defects in metals by making two exposures on a single film. This method enables a direct measurement of the distance between the two images of the defect to be made, and from this the vertical

distance of the flaw from the surface can be calculated. Tests showed that this vertical distance could often be determined by this technique with an accuracy of $\pm 3\%$. Larger errors must be expected when the flaws are of irregular shape.

The Ar″ Range in Some Iron-Cobalt-Tungsten Alloys. W. P. Sykes. (American Society for Metals, Oct., 1942, Preprint No. 3). The author points out that the $\gamma \longrightarrow \alpha$ transformation of carbon-free iron-cobalt-tungsten alloys takes place throughout a range of temperature corresponding to the Ar″ range of steels. By hardness tests and micrographic examination he found this range to lie between 525° and 350° C. for an alloy with 53% of iron, 30% of cobalt and 17% of tungsten. This range is shifted to much lower temperatures by the addition of chromium. Thus the upper limit of the Ar″ range of an alloy with 30% of cobalt, 17% of tungsten, 4% of chromium and 49% of iron was depressed to about 250° C., whilst the lower limit seemed to lie below the temperature of liquid air.

The Alpha Iron Lattice Parameter as Affected by Molybdenum, and an Introduction to the Problem of the Partition of Molybdenum in Steel. F. E. Bowman, R. M. Parke and A. J. Herzig. (American Society for Metals, Oct., 1942, Preprint No. 14). The authors discuss methods of determining quantitatively the distribution of molybdenum between cementite and ferrite in steel. The earlier work done on this problem is reviewed and the adaptability of the X-ray diffraction technique for this purpose is considered. A curve showing the relation between the molybdenum content and the lattice parameter of α-iron is presented.

The Effect of Molybdenum on the Isothermal, Subcritical Transformation of Austenite in Eutectoid and Hypereutectoid Steels. J. R. Blanchard, R. M. Parke and A. J. Herzig. (American Society for Metals, Oct., 1942, Preprint No. 15). To obtain an insight into the function of molybdenum in the decomposition of austenite at constant subcritical temperatures the authors constructed S-curves for eutectoid and hypereutectoid steels with molybdenum contents up to 0·75%. These curves were found to have a " bay " in the region of about 593° C. This was caused by the notably greater effect of molybdenum on the rate of transformation of austenite to pearlite than that on the rate of the austenite-bainite transformation. Molybdenum also markedly increases the interlamellar spacing of pearlite at 649° C. in both eutectoid and hypereutectoid steels.

The Effect of Molybdenum on the Rate of Diffusion of Carbon in Austenite. J. L. Ham, R. M. Parke and A. J. Herzig. (American Society for Metals, Oct., 1942, Preprint No. 16). The authors determined the rate of diffusion of carbon in austenite containing 0·80% of molybdenum at 982°, 1093° and 1204° C. A comparison of these rates with those obtained for plain carbon steels by other investigators revealed that at round about 1093° C. molybdenum

has little or no effect on the rate of carbon diffusion; at higher temperatures the rate is slightly accelerated, and at lower temperatures it is retarded by the presence of molybdenum. The possibility of measuring the diffusion coefficients of both constituents of a binary diffusion system by a consideration of changes in shape or length of the specimen is discussed.

A Metallographic Study of the Formation of Austenite from Aggregates of Ferrite and Cementite in an Iron-Carbon Alloy of 0·5 Per Cent. Carbon. T. G. Digges and S. J. Rosenberg. (American Society for Metals, Oct., 1942, Preprint No. 20). The authors studied the nucleation and growth of austenite on heating a high-purity alloy of iron and carbon containing 0·5% of carbon. The changes that occurred in both fine pearlite and an aggregate of spheroidised cementite and ferrite were followed by the differential heating of small specimens *in vacuo* at various rates to temperatures within and slightly above the Ac_1–Ac_3 transformation range and quenching in helium. On heating fine pearlite, austenite was nucleated at the interfaces of ferrite and carbide, preferentially at the boundaries of pearlite and pro-eutectoid ferrite and at the boundaries of the pearlite colonies. It was also occasionally nucleated within the pearlite colonies. Finger-like growths occurred usually in the direction of the lamellæ, but sometimes across the lamellæ. Regardless of the rate at which the alloy was heated through the Ac_1 transformation, austenite nuclei formed at numerous ferrite-carbide interfaces so that in the initial stage the austenite was always fine-grained. Rapid grain growth may occur in the Ac_1–Ac_3 transformation range by the absorption or coalescence of the grains initially formed; if the rate of heating through this range was extremely rapid, this grain growth was to a great extent inhibited and the resulting austenite was relatively fine-grained at temperatures considerably above Ac_3. If heating was less rapid, grain growth was not inhibited and the resulting austenite was very coarse-grained. The rate of growth, not the rate of nucleation, is the predominating factor in establishing the final size of the austenite grains of this alloy.

Influence of Initial Structure and Rate of Heating on the Austenitic Grain Size of 0·5 Per Cent Carbon Steels and Iron-Carbon Alloy. T. G. Digges and S. J. Rosenberg. (American Society for Metals, Oct., 1942, Preprint No. 21). Tests were made to determine the influence of variations in initial structure and rate of heating through the transformation temperature range on the grain sizes at 800° and 870° C. of a high-purity alloy of iron and carbon and two commercial steels all containing 0·5% of carbon. Variations in initial structure had no effect on the grain size of the iron-carbon alloy. Although the initial structure had some influence on the grain size of the steels, no correlation was found between the grain size and the spacing of pearlite or the form and distribution of the carbides. The rate of heating had a pronounced effect on the grain

size of the iron-carbon alloy and in some cases on that of the steels. The finest grains were obtained in the steels with slow rates of heating, but the reverse trend was observed with the iron-carbon alloy.

The Mechanism and the Rate of Formation of Austenite from Ferrite-Cementite Aggregates. J. A. Roberts and R. F. Mehl. (American Society for Metals, Oct., 1942, Preprint No. 22). The authors give an account of a series of experiments designed to establish the mechanism of the formation of austenite and to measure the isothermal rate of formation of austenite from aggregates of ferrite and cementite in eutectoid steels. The rates of formation are analysed in terms of the rates of nucleation and grain growth. These two rates were both found to vary with the initial structure, thus differing from the austenite $\rightarrow$ pearlite transformation in which the rate of growth is insensitive to structure whilst the rate of nucleation is structure-sensitive. The austenite formed in eutectoid steels is not homogeneous when the ferrite disappears as a structural constituent, for undissolved carbide remains, the solution rate of which is dependent upon both time and temperature. Carbon concentration gradients exist for appreciable times after the carbide itself is no longer visible in the microstructure.

The effect of temperature, initial structure and deoxidation practice on the rate of formation of austenite is described, and a method of calculating the initial grain size of the austenite and the rate of growth is included.

A Study of the Iron-Rich Iron-Manganese Alloys. A. R. Troiano and F. T. McGuire. (American Society for Metals, Oct., 1942, Preprint No. 27). The authors describe an X-ray investigation of specimens and powders of iron-manganese alloys of high purity containing up to 50% of manganese, the object being to determine the α and $\alpha + \gamma$ phase boundaries of the iron-manganese system. Precision lattice-constant determinations were made by X-ray diffraction methods and these were correlated with the results of a microscopical examination. Specimens were quenched very rapidly in water after prolonged heating at the lower temperatures and short-time heating at high temperatures (*e.g.*, 2 years at 300° C., 1 day at 800° C. and 1 hr. at 900° C.). At 300° C., two years were insufficient to attain equilibrium. Direct evidence is presented of the existence of two types of α solid solutions (equilibrium and supersaturated α solid solutions). The disturbing and sometimes misleading effects of supersaturated solid solutions are discussed and evaluated. The results of deformation and long-time annealing studies of the ε phase lead to the conclusion that this phase is not stable.

The Induction Furnace as a High Temperature Calorimeter and the Heat of Solution of Silicon in Liquid Iron. J. Chipman and N. J. Grant. (American Society for Metals, Oct., 1942, Preprint No. 28). The authors describe how they determined the heat of solution of silicon in liquid iron using a H.F. induction furnace containing 65

to 90 lb. of liquid metal as a calorimeter. The rise of temperature in the bath caused by the addition of a weighed amount of silicon was measured by a tungsten-molybdenum thermocouple. Assuming the heat of deoxidation of iron by liquid silicon at 1600° C. to be 180,000 cal. evolved per mol. of silica formed, the heat of solution of liquid silicon in liquid iron was found to be 29,000 cal. evolved per g.-atom of silicon. From the results obtained and supplementary data, the temperature changes accompanying the addition of several grades of ferro-silicon to molten iron at 1600° C., with and without deoxidation, were calculated.

The Kinetics of Austenite Decomposition in High Speed Steel. P. Gordon, M. Cohen and R. S. Rose. (American Society for Metals, Oct., 1942, Preprint No. 30). The authors studied the decomposition of the austenite in two high-speed steels (a 6%-tungsten 6%-chromium 2%-vanadium 5%-molybdenum steel and an 18%-tungsten 4%-chromium 1%-vanadium steel). With the aid of a suitable dilatometer it was possible to observe the transformations while cooling to, holding at, and cooling from the hot-quenching temperature. A quantitative metallographic technique was employed to convert the dilatation measurements to percentage transformation of the austenite on an absolute basis. The transformation curves for both steels are very much alike, and consist of two families of S-curves (actually more like C-curves). In the upper transformation range the product is pearlite, preceded or accompanied by carbide precipitation. The lower group of curves represents the decomposition of austenite into bainite. The formation of bainite has a stabilising influence on the remaining austenite because the transformation does not go to completion and the martensite point of the remaining austenite is depressed, in some cases even to below room temperature. On hot-quenching into the martensite range, martensite forms during the cooling to the holding temperature; after the holding temperature is reached, a two-stage isothermal transformation takes place. The first stage proceeds slowly with the appearance of bainite plates in the microstructural regions occupied by the martensite; this transformation is small in extent. The second stage results in the general formation of bainite throughout the structure. Austenite decomposition does not take place on hot-quenching into the " bay " between the two families of S-curves, even if the holding time is prolonged to 165 hr.

Study of Inverse Segregation Suggests New Method of Making Certain Alloys. M. L. Samuels, A. R. Elsea and K. Grube. (American Society for Metals, Oct., 1942, Preprint No. 36). The authors studied the freezing of an alloy of 50% of iron and 50% of copper. This alloy possesses a very wide solidification range and freezes as two distinct structural constituents. Iron dendrites containing some copper in solid solution begin to form at about 1440° C. and the copper-rich phase does not solidify until the temperature has dropped to about 1095° C. A copper-rich skin on the lower outside

surfaces of some castings was thought to have originated from inter-dendritic flow during the semi-liquid stage. It was found possible, by reheating into this stage, to displace the low-melting-point phase with other metals, such as silver or lead, which are not miscible with iron in the molten state.

CORROSION OF IRON AND STEEL

(Continued from pp. 66 A–68 A)

The Effect of Zinc on the Corrosion-Fatigue Life of Steel. N. Stuart and U. R. Evans. (Iron and Steel Institute, 1943, this Journal, Section I.). Earlier work at Cambridge and elsewhere has shown that on steel wetted with nearly neutral chloride solutions contact with zinc prolongs the fatigue life. There appeared, however, a danger that in acid liquids contact with zinc might increase the hydrogen charge and thus enhance the fragility. Most of the demonstrations of brittleness caused by a hydrogen charge in steel refer to stresses which, in the absence of hydrogen, would be sufficient to cause plastic flow; it seemed important to ascertain whether, within the elastic range, contact with zinc improved or shortened the life of steels bent in the presence of acid of different concentrations; the effect of nickel contacts was also studied.

A machine was set up which permitted the alternating bending of twenty thin steel strips simultaneously in a thermostat room, so as to give mean values which would be reliable—despite the scatter of results invariably met with in work of this kind.

It was found that on cold-rolled steel (0·26% carbon) wetted with relatively strong acid, a zinc contact increased the fatigue life of the steel. At 0·001N and 0·00125N, contact with zinc had no significant influence, but here the life is relatively long in any case. Steel previously charged with hydrogen by cathodic treatment showed a long fatigue life, even though the gas charge far exceeded that which would be produced by contact with zinc. It is concluded that a hydrogen charge is not dangerous if the alternating stressing does not exceed the range needed to produce permanent set. Specimens exposed to the atmosphere in contact with zinc suffered much less visible attack than those without zinc protectors, but the fatigue life was not increased.

It is concluded that contact with zinc may have value in some conditions, and that the dangers arising from a hydrogen charge are not serious.

Corrosion of Water Pipes in a Steel Mill. C. L. Clark and W. J. Nungester. (American Society for Metals, Oct., 1942, Preprint No. 26). The authors report the results of an investigation undertaken to determine the cause of severe corrosion in the cooling water pipes

of a rolling mill. Chemical analysis of the corrosion products showed that both sulphides and free sulphur were present. As neither of these were present in the original well water, the action of sulphite reducing bacteria was indicated. Circumstantial evidence and a bacteriological investigation confirmed that this theory was correct.

Corrosion of Boiler Tubes. T. H. Turner. (Institution of Mechanical Engineers: Engineer, 1942, vol. 174, Nov. 27, pp. 446–448; Dec. 4, pp. 466–468). The author summarises experience gained by the London and North-Eastern Railway in the study of the corrosion of boiler tubes and the treatment of feed waters. He makes the following recommendations: (1) New tubes should be scale-free with a pickled or shot-blasted surface and there should be 0·2–0·5% of copper in the steel (2) New ends for second-hand tubes should be affixed by flash-butt welding; stretching tubes is not recommended. (3) The new ends on second-hand tubes should be fitted to the fire-box. (4) Shot-blasting should be carried out on both inside and outside surfaces of boiler shell and fire-box. (5) Remember that permanent hardness in waters causes much more damage to boilers than temporary hardness. (5) Add the feed near the surface of the water in the boiler to allow escape of gases into the steam. (7) Fit a trough below the feed entrance pipe to aid the release of gases and to catch some of the sludge. (8) Use boiler-water control tests as part of the normal routine for all boilers. (9) Maintain zero hardness and a definite alkalinity in the boiler water, paying attention to the possibilities of caustic embrittlement.

BOOK NOTICE

(Continued from pp. 69 A–70 A)

ASSOCIATION OF IRON AND STEEL ENGINEERS: *Specifications for Electric Overhead Travelling Cranes for Steel Mill Service.* 4to. Pp. 29. Pittsburgh, 1942.

The Association of Iron and Steel Engineers sponsored the first specifications for steel-mill cranes in 1910. After several revisions a special committee was set up in 1938, and the results of the Committee's work are embodied in the present revised specifications. Many of the items contained in these are published for the first time. The section on girder design is based on the research and studies made by Mr. Madesen at Lehigh University, and the formulæ given recognise all the lateral and horizontal forces that must be resisted, and are not modifications of standard column formula or those used in the design of bridge structures.

The section on wheel loadings is based on the satisfactory operation of crane wheels and rail sections submitted by many users of these cranes, as well as the recommendation of the builders of cranes and the manufacturers of wheels. Investigation of this subject showed the necessity of using rails designed for heavy loads at low speeds and capable of resisting high lateral thrusts.

The proper application of anti-friction bearings to crane wheels is covered by a table of ratings. The deflection of the axles and condition of the runway rails greatly affect the life of anti-friction bearings. These tables have been approved by the bearing manufacturers and have been checked with operating records of satisfactory installations in the mills.

The subject of bridge drives was covered in a symposium held in Pittsburgh when 13 papers were given by authorities on various phases of this subject. These papers are included in the Association Yearbook for 1940. The section of the specifications on this subject is based on information submitted at this symposium plus the experience of many operators.

MINERAL RESOURCES

(Continued from pp. 37 A–38 A)

Chromite in South-eastern Manitoba. J. P. de Wet. (Canadian Mining Journal, 1942, vol. 63, Oct., pp. 657–658). The author gives an account of the discovery in 1942 and the geology of low-grade deposits of chromite in South-eastern Manitoba. Assays have shown from 5% to 25% of chromic oxide and a chromium/iron ratio of 1·82/1.

Tungsten. D. C. McLaren. (Canadian Mining Journal, 1942, vol. 63, Oct., pp. 627–639). The author discusses the occurrence in Canada of minerals containing tungsten and describes methods of concentrating tungsten ores, in particular those in use at the plant of the Hollinger Consolidated Gold Mines, Ltd.

The Future of Indian Coking Coals. A. Lahiri. (Coke and Smokeless-Fuel Age, 1942, vol. 4, Oct., pp. 208–209, 214). The author reviews authentic published statements relating to the reserves, production and consumption of coking coals in India. The current production of coal is about 29 million tons per annum, of which about 13 million tons are of coking quality. At this rate of production, and taking into account the present wasteful and inefficient methods of mining, the reserves can scarcely last more than another sixty years. The need is emphasised for legislation to enforce the use of inferior grades of coal for steam-raising and other purposes for which coking coal is now being applied.

Geology of the Forest of Dean Coal and Iron-Ore Fields. F. M. Trotter and W. C. C. Rose. (Geological Survey of Great Britain, 1942 : H.M. Stationery Office). This is a short memoir dealing primarily with the geology of the coal and iron-ore field of the Forest of Dean, Gloucestershire; it is based on 6-in.-to-the-mile geological maps produced in the period 1933–38.

Wolfram in Nigeria : with Notes on Cassiterite, Wolfram and Columbite Zones. H. L. Haag. (Bulletin of the Institution of Mining and Metallurgy, 1943, Jan., pp. 1–34). The author gives an account of the geology of ores containing tungsten which are found in Nigeria in association with the well-known tin deposits. During the war of 1914–18 a small tonnage of wolfram was produced from two veins, after that, production fell off until about 1935; by 1939 the output had risen to nearly 20 tons per month. In the aggregate little prospecting has yet been done. The deposits so far found are mostly small, and not sufficiently attractive to justify much capital expenditure.

Occurrence and Production of Molybdenum. J. W. Vanderwilt. (Iron Age, 1942, vol. 150, Oct. 1, pp. 104–107, 184–197). The author reviews the occurrence of molybdenite (MoS_2) and methods

of producing molybdenum. World production of molybdenum has risen to about 17,000 tons per annum. There are only eight commercially important producers of molybdenite of which five are in the United States, and one each in Mexico, Norway and French Morocco.

ORES—MINING AND TREATMENT

(Continued from pp. 38 A–39 A)

Preparatory Work for Ore Mining. O. Berggren. (Jernkontorets Annaler, 1942, vol. 126, No. 7, pp. 301–326). (In Swedish). The author explains and gives examples of calculations for determining the most economical methods of sinking shafts and carrying out other preparatory work for mining iron ore.

The Experimental Determination of the Degree of Efficiency of the Work Expended when Drilling at Different Air Pressures. E. Rothelius. (Jernkontorets Annaler, 1942, vol. 126, No. 2, pp. 71–81). (In Swedish). The author reports the results of an investigation of the efficiency of a rock-drilling machine when operated at different air pressures. The tests were made in Stockholm granite using 1-in.-dia. drill steel with apparatus with which the following items could be determined: (1) The pressure of the air fed to the machine; (2) the amount of air used to drive a hole 250 mm. deep; (3) the temperature of the air entering and leaving the machine; (4) the time taken to drill the hole; (5) the diameter of the crown of the bit before and after each test; and (6) the volume of the hole.

Measuring the Air Consumption of Loading Machines. T. Jensfelt and P. V. Villner. (Jernkontorets Annaler, 1942, vol. 126, No. 4, pp. 115–130). (In Swedish). The authors describe an air-metering apparatus designed for measuring the air consumption of pneumatic ore-loading machines used in some of the Swedish iron ore mines. The average consumption of the machines tested was about 5 cu. m. per min. or about 7 cu. m. per ton of ore loaded; very brief peak loads of up to 10 cu. m. per min. were measured.

Iron-Ore Production in Central Sweden since the End of the Nineteenth Century. G. Sidenvall. (Jernkontorets Annaler, 1942, vol. 126, No. 6, pp. 177–216). (In Swedish). The author gives a comprehensive review of the mining of iron ore in central Sweden from 1890 to 1938. A very substantial increase in the quantity mined took place about the turn of the century, due largely to the extension of the railway system and the application of power-driven machinery. The average annual quantity mined in the period 1833–1910 was 773,000 tons which increased to 2,444,000 tons for the period 1911–1938, and for the last few years of the latter period this average had risen to about 4,000,000 tons. Tables

and graphs of the production and labour employed in different areas are presented which include separate data for the manganiferous ores and for the ores with high, medium and low phosphorus contents.

Industrial-Scale Tests on Hematite Flotation. G. G. Bring and I. Janelid. (Jernkontorets Annaler, 1942, vol. 126, No. 5, pp. 143–160). (In Swedish). The authors give an account of some full-scale tests on the continuous flotation process of concentrating Swedish hematite. 100-ton lots of ore from the Stripa mine were used, the method being that described for an earlier small-scale investigation (*see* Journ. I. and S.I., 1941, No. II., p. 106 A). These tests proved that there was no difficulty whatever in producing a 65–66% concentrate from a 35% iron ore by the flotation method described. There was some difficulty in getting rid of the phosphorus in the apatite so as to keep that in the concentrate below 0·005%.

REFRACTORY MATERIALS

(Continued from pp. 73 A–74 A)

Refractories in War-Time. T. W. Howie. (Metallurgia, 1942, vol. 27, Dec., pp. 59–61). The author reviews developments in refractory materials, particularly those which have been stimulated by war-time conditions. The possibility of producing forsterite bricks from serpentine rock which occurs in the Shetland Islands and the Western Highlands of Scotland is suggested. Considerable improvements might also be made by further standardisation, especially of electric-arc furnace roof-bricks and in casting-pit refractories.

Acid and Basic Bessemer Refractories. J. H. Chesters. (Iron Age, 1942, vol. 150, Nov. 5, pp. 43–48). The author discusses English and American practice in the lining of acid and basic Bessemer converters and mixers. Most American converters are lined with sandstone, and it is surprising that they can be safely lined with material containing substantial quantities of raw quartz when they operate at such high temperatures. Conversion of this quartz to cristobalite must take place, at least in the surface layers, and considerable expansion occurs. It is probably the cylindrical shape of the converter body which makes expansion possible without loss of shape or serious spalling. The basic converter is lined with tarred " basic " (dolomite calcined at a high temperature), which may be in the form of blocks or a monolithic ramming. For the latter type of lining the importance of using the optimum tar content cannot be too highly stressed; the amount varies between 5% and 7%, and changes within these limits should be made to allow for the different conditions at different points in the vessel

lining. The lining is broken in for service by charging with hot coke, and subsequently lime and iron, and blowing until the iron is converted into a slag of the following approximate analysis: FeO 30%, Fe_2O_3 20%, CaO 25%, MgO 15%, SiO_2 6% and Al_2O_3 4%.

British Standard Test Code for Kilns for Heavy Clay Ware, Including Refractory Materials. (British Standards Institution, No. 1081–1942). This test code has been drawn up to indicate the methods which should be adopted and the data which should be obtained in the testing of intermittent, continuous car tunnel, ring tunnel and chamber continuous kilns used in the heavy clay and refractory industries.

FUEL

(Continued from pp. 39 A–41 A)

A Review of Recent Progress in Heat Transfer. C. H. Lander. (Proceedings of the Institution of Mechanical Engineers, 1942, vol. 148, No. 3, pp. 81–112). The author discusses the increase in knowledge of heat transfer during the last thirty years. Complete rationalisation is still not possible, but dimensional methods similar to those used in ship and aircraft design are being applied more and more generally to heat-transfer problems. By their aid the practical range of any set of data may be greatly widened. For example, experiments made under pressure on surfaces only a few inches high may be used to deduce the heat transfer for surfaces several feet high at atmospheric pressure. Selected cases dealt with include: Forced convection for banks of tubes and beds of broken solids, and the relation between heat transfer and friction; natural convection from vertical and horizontal surfaces and across fluid layers; heat transfer in the drop and film condensation of steam, and in film and nucleate boiling; evaporation and its relation to convection; emissive powers of surfaces for radiation; and radiation from non-luminous gases.

An Investigation on the Heat Transfer in Rolling-Mill Furnaces with Reference to the Soaking of Blooms. A. Schack. (Iron and Steel Institute, 1943, Translation Series, No. 124). An abridged English translation is presented of a paper which appeared in Archiv für das Eisenhüttenwesen, 1930, vol. 4, Jan., pp. 333–342 (*see* Journ. I. and S.I., 1931, No. I., p. 639).

Furnace Efficiency. (Coke and Smokeless-Fuel Age, 1942, vol. 4, Dec., pp. 245–247). The practical meaning of the term efficiency as applied to industrial furnaces is discussed, and the difficulty of calculating the efficiencies of heat-treatment and other furnaces is explained. The formulæ put forward by H. Schwiedessen in a recent paper on the thermal efficiency of industrial furnaces are considered (*see* Journ. I. and S.I., 1942, No. II., p. 4 A).

The Effective Heat Requirement of a Furnace. G. Neumann. (Iron and Steel Institute, 1943, Translation Series, No. 120). An English translation is presented of a paper which appeared in Archiv für das Eisenhüttenwesen, 1932, vol. 5, Mar., pp. 471–475 (*see* Journ. I. and S.I., 1932, No. I., p. 473).

The Construction and Operation of Furnaces with Particular Reference to Heating Furnaces. A. Schack. (Iron and Steel Institute, 1943, Translation Series, No. 118). An English translation is presented of a paper which appeared in Archiv für das Eisenhüttenwesen, 1931, vol. 5, Oct., pp. 193–208 (*see* Journ. I. and S.I., 1932, No. I., p. 472).

The Carburetting of Long-Distance Gas with Liquid Coal-Tar Pitch and Pitch Additions to the Fuel in the Operation of Open-Hearth Furnaces. I. Plant for Carburetting Long-Distance Gas with Coal Tar Pitch when Melting in Open-Hearth Furnaces. P. Bremer. (Stahl und Eisen, 1942, vol. 62, Oct. 29, pp. 913–917). The author describes and illustrates modified and improved equipment for supplying liquid pitch to long-distance-gas burners for open-hearth furnaces, and discusses some of the developments made since the publication of an earlier report (*see* Journ. I. and S.I., 1938, No. I., p. 177 A). Some consumption data are presented. For a basic open-hearth furnace producing 150 tons of steel per day the average consumptions per ton of steel over a long period in 1940–41 were gas 270 cu. m. and pitch 16 kg., the mixture being such that the pitch produced 11% of the total heat.

The Carburetting of Long-Distance Gas with Liquid Coal-Tar Pitch and Pitch Additions to the Fuel in the Operation of Open-Hearth Furnaces. II. Pitch Additions to the Fuel in Open-Hearth Plant. C. Meier-Cortes. (Stahl und Eisen, 1942, vol. 62, Oct. 29, pp. 917–920). The author describes how burners for coal-tar pitch with the necessary heating and pumping equipment were fitted to an open-hearth furnace, which had been fired with a mixture of producer gas and coke-oven gas from an overloaded ring main. In this case the pitch acted not only as a carburetting agent, but also as part of the fuel to supply the heat required. Two pairs of water-cooled nozzles with 1·75-mm.-dia. orifices were fitted, one at each end of the furnace; these burners were positioned so that the pitch flames from two burners at one end met at an angle of 70°, for an angle of 90° had been found unsatisfactory. The pitch was heated with a hot-oil-circulation system kept at about 175° C., and it was atomised by compressed air at 6 atm. heated to 250° C. In designing the equipment for a 50-ton furnace it had been calculated that 187 kg. of pitch per hr. would be required to produce the same amount of heat as 400 cu. m. of coke-oven gas. In practice, however, it was found that this consumption could be reduced to 100 kg. per hr. without lowering the production. The reason for this probably is that the rate of heat transfer from the luminous pitch flame is greater than with a coke-oven-gas flame. After initial trials and

adjustments, satisfactory equipment and an economical method of operation were developed.

The Top Horizontal Flue. (Coke and Smokeless-Fuel Age, 1942, vol. 4, Oct., pp. 210–214). A description is given of attempts which have been made to improve the design of coke-oven flues so as to produce the optimum conditions in the free space above the charge for the formation of benzol. The Koppers top horizontal flue for twin-flue ovens is described; in this the flow of gases from the vertical flues into the upper flue can be adjusted by dampers and the temperature at the top of the oven can thus be controlled. Experience gained in Russian coke-oven practice as reported by J. B. Peisakhson is quoted (*see* Iron and Steel Institute, Translation Series, No. 58).

The Dry Cooling of Coke. (Coke and Smokeless-Fuel Age, 1942, vol. 4, Nov., pp. 224–227; Dec., pp. 241–244). In the first article of this series descriptions are given of some coke-cooling plants operating on the Sulzer dry-cooling system. There are at present thirteen bunker-type Sulzer plants operating, or under construction, at gas-works. A large unit with a capacity of about 700 tons of coke per day operates at the Ford plant at Dagenham. This plant contains two cooling units which usually work in parallel and cool the coke from 980° C. to 300° C. The average steam production is 1100 lb. per ton of coke cooled; the steam pressure is 200 lb. per sq. in., and its temperature after superheating is 315° C. In the second article a description of the Collin system of cooling coke is given. This process is used, as far as is known, at three coke-oven plants, two in Germany and one at the Iscor Works at Pretoria. A battery of cooling chambers is employed, placed in front of and below the coke-ovens. Each chamber serves three ovens, and the coke is discharged direct from the ovens into the chambers with a specially designed guide fitted with a swivelling end-shield to conduct the coke from any one of three ovens. The chambers are fitted with cast-iron step-grates upon which the coke rests, and are connected by valves to a common main in a closed circuit, which also includes a boiler, superheater and feed-water heater. The inert circulating gas, which is air deprived of its oxygen, is heated by the coke, and then communicates its heat to the other plant in the cycle.

The reduction in cooling time that has been effected in the unit chamber type of plant has made this design suitable for even the largest capacities. There is every prospect of an increased use of dry cooling in steelworks' coke-ovens and in colliery coke-ovens producing for the iron and steel industry.

Producer Gas. L. Clegg. (Journal of the Junior Institution of Engineers, 1942, vol. 53, Dec., pp. 55–76). The author gives a comprehensive account of producer-gas practice, discussing in turn: (*a*) The effect of oxygen or air upon hot carbon; (*b*) the effect of steam upon hot carbon; (*c*) the formation of combustible com-

ponents of producer gas other than those formed by means of air or steam. He describes different types of gas producers and auxiliary equipment.

PRODUCTION OF IRON

(Continued from pp. 75 A–76 A)

The Planning of an Ironworks for Norrbotten. N. Danielsen. (Teknisk Tidskrift, 1941, vol. 71, Dec. 20, pp. 541–544). (In Swedish). The idea of building an ironworks in the province of Norrbotten in Northern Sweden has been put forward more than once, but nothing definite came of it until 1940, when the Norrbottens Järnverk Aktiebolag was formed with the Swedish State as the sole shareholder. In this paper the author outlines some of the plans which have been put forward and gives some information on the decisions of the board of the above company. It has been decided to erect a works at Svartön near Luleå, consisting of two electric blast-furnaces capable of producing 60,000 tons of pig iron per annum, two basic Bessemer converters and an electric steel furnace. The phosphoric ores from the Norrbotten field will be used with coke or a mixture of coke with up to 75% of charcoal for reduction. The electric power requirements are estimated at about 27,000 kW. Provision has been made for putting in a plant to make granulated iron by the Rennerfelt-Kalling process if this should be thought advisable at a later date.

East Texas to Become a Pig Iron Producer. G. H. Anderson. (Mining and Metallurgy, 1942, vol. 23, Aug., pp. 417–419). The United States War Production Board has recently sanctioned the erection of a blast-furnace, a battery of coke-ovens, and an ore-beneficiation plant in north-eastern Texas. In this article the author gives a brief description of the district from the iron-making point of view with some particulars of the ore and coking-coal deposits and the proposed method of beneficiation.

The Preparation and Smelting of Minette Ore and Blast-Furnace Flue Dust. J. Paquet and M. Steffes. (Iron and Steel Institute, 1943, Translation Series No. 122). This is an English translation of a paper which was published in Stahl und Eisen, 1942, vol. 62, July 23, pp. 621–631. (*See* Journ I. and S.I., 1942, No. II., p. 195 A).

Increasing Blast-Furnace Efficiency with a Simultaneous Saving in Coke. E. Senfter. (Stahl und Eisen, 1942, vol. 62, Dec. 10, pp. 1041–1052). The author discusses numerous factors which affect the consumption of coke in the blast-furnace, such as the preparation of ores by crushing, screening and sintering. He directs attention to the consumption of power and fuel in these processes and describes methods of handling coke between the coke-ovens and the blast-furnace so as to produce a minimum of breeze ;

a scheme for charging is described which increases the efficiency of the early stages of the process taking place in the upper part of the blast-furnace.

The Valuation of the Charge for the Production of Pig Iron in the Blast-Furnace. H. Bansen and E. Krebs. (Iron and Steel Institute, 1943, Translation Series No. 123). An English translation is presented of a paper which appeared in Archiv für das Eisenhüttenwesen, 1940, vol. 14, Sept., pp. 91–103 (*see* Journ. I. and S.I., 1941, No. II., p. 194 A).

FOUNDRY PRACTICE.

(Continued from pp. 76 A–80 A)

Modern Foundry Work. R. J. Richardson. (Proceedings of the South Wales Institute of Engineers, 1943, vol. 58, No. 3, pp. 131–166). After a short review of the early history of founding, the author surveys the position now reached in foundry development, describing sand testing and control, moulding machines, the layout of a casting bay in an iron foundry and the dressing of castings. In conclusion he describes the casting of steel stud-link chains, anchors and bomb-cases.

What is Briquetting Current Practice? W. A. Phair. (Iron Age, 1942, vol. 150, Oct. 29, pp. 31–33). The author summarises the information received as a result of a questionnaire submitted to twelve American plants at which the briquetting of cast-iron borings and steel turnings is carried out. Data on the briquette size, weight and density, and the output per shift are presented. All the plants agreed that only minor changes in cupola charging and melting practice were necessary, and that the use of briquettes lowered the cost of the metal at the spout.

Ladle Metallurgy. J. H. Williams. (Institute of British Foundrymen: Foundry Trade Journal, 1942, vol. 68, Dec. 17, pp. 345–347). The author records some of his experiences in making ladle additions to molten iron tapped from cupolas. The silicon content could be raised 0·5% by ferro-silicon additions without cooling the iron too much. Manganese additions could be readily made, but the alloy added should be carbon-free, because the time in the ladle was much too short for the dissociation of manganese carbides. Chromium additions were the most difficult to make, and even with finely crushed ferro-chromium well rabbled into the metal, up to 15% of the amount added might be lost; the best method was to add it in granular form, with no dust, slowly and directly to the ladle while the metal was being teemed. Nickel was easily added in the form of shot. Molybdenum additions are also easy to make at the spout, but a fair quantity of iron must

be allowed to accumulate in the ladle before adding the ferro-molybdenum.

Electric Furnaces in the Manufacture of High-Duty Cast Iron. T. R. Twigger. (Institute of British Foundrymen : Foundry Trade Journal, 1942, vol. 69, Jan. 7, pp. 3–7 ; Jan. 14, pp. 25–28). The author discusses experience gained in the operation of electric furnaces at a foundry making piston rings by the centrifugal casting of high-duty iron. Two principal methods are in use : (1) Production of molten metal, either from a cold charge, or more often by modifying cupola metal of such a composition that the desired final composition can be achieved by mixing a percentage of the special electric furnace metal with the cupola metal. This is the method usually practised with the rocking arc furnace. Since the supply must be continuous, two electric furnaces must be used, or, when using one electric furnace, the metal may be stored in a crucible furnace. (2) The continuous duplexing of molten cupola metal—in this case molten metal as near as possible to the desired final composition is melted in a cupola, and transferred at 10-min. intervals to a 'Lectromelt furnace in which a 7-cwt. cold charge has already been melted. Alloy or steel additions are made as necessary, and the metal is withdrawn, usually at 10-min. intervals, for casting. A specimen time-table is presented showing how the electric furnace and cupola operations are synchronised, and details are also given of how typical charges are made up, and of current and cooling water consumptions and labour requirements.

Graphitisation of Martensite on Heating. A. Hultgren and O. Edström. (Jernkontorets Annaler, 1942, vol. 126, No. 3, pp. 83–107). (In Swedish). The authors studied the effect of a preliminary heating and quenching treatment on cast iron before malleablising it. By prequenching, the number of graphite particles after malleablising is increased from about 100 to 7500–35,000 per sq. mm., the number depending on the quenching temperature and the malleablising treatment. Full details of the experiments on ordinary malleable iron and on iron alloyed with small amounts of nickel, chromium and molybdenum are given, together with micrographs of the structures obtained. On examining the microstructure at different stages of malleablising, no case was observed of a graphite nucleus appearing within a cementite area. The nuclei formed in the matrix and, so it seemed, preferentially at the matrix-cementite boundaries. Tensile tests on pre-quenched and malleablised specimens showed a normal tensile strength but rather poor elongation, 6–7% for unalloyed and rather less for alloyed iron.

Graphitization of Cementite in Cupola White Iron. N. A. Ziegler, W. L. Meinhart and A. J. Deacon. (Transactions of the American Foundrymen's Association, 1942, vol. 49, Mar., pp. 449–472). The authors studied the graphitisation of cast iron at various stages during the malleablising process. This was done by determining

the growth of the white iron with a dilatometer and correlating the data with the chemical analysis and observations of the microstructure. The specimens of white iron contained combined carbon 2·98%, graphitic carbon 0·18%, silicon 0·91%, manganese 0·47%, sulphur 0·92% and phosphorus 0·17%. The results obtained confirmed those of previous investigators who have found that graphitisation of white iron occurs in two stages. The first stage is the graphitisation of excess cementite, the rate of which is determined by the temperature above the transformation range, the most efficient one being 930–980° C. The second stage, or the graphitisation of pearlite, takes place in, and just below, the eutectoid range, *i.e.*, at about 700–730° C. In the present tests only the excess cementite and limited amounts of carbon held in solution by austenite were graphitised in the first stage. In the second stage the graphitisation progressed more slowly, but, since there was less carbon held in solid solution, it was more complete. The most rapid phase of the second-stage graphitisation occurred simultaneously with the formation of pearlite from austenite, hence the most efficient way of carrying it to completion is to reduce the holding temperature in steps within the eutectoid range.

Graphitization Symposium—I. The Principles of Graphitization. H. A. Schwartz. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 1–23). The author discusses the theory of the process of making malleable cast iron. He first shows the effects of time, temperature and composition on the structure produced when cast irons solidify, illustrating this with micrographs, and then explains the effect of temperature on the decomposition of iron carbide, graphite precipitation and how various factors influence the nucleation and growth of the carbon nodules. Finally, some points relating to graphitisable steels are dealt with. The commercial graphitisable steels contain about 1·0–1·5% of carbon and about the same amount of silicon; when heated into the temperature range of the first stage of malleable annealing, they contain no excess of cementite; graphitisation cannot therefore begin by the precipitation of graphite at the junction of the cementite and the solid solution. Apparently in such material the graphite nuclei form round oxides or sulphides. The heat treatment in the second stage of annealing these steels must be controlled so as to give the desired structure to the matrix of the product.

Graphitization Symposium—II. The Suppression of Graphitization by Supercooling. C. H. Junge. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 24–29). The author describes what happens when a liquid freezes, taking a pure metal as an example, and explains the phenomenon of supercooling; he then applies these explanations to the freezing of liquid iron containing silicon and carbon, and stresses the importance of supercooling in the suppression of graphite formation.

Graphitization Symposium—III. The Effect of Composition on the Annealing of White Cast Iron. W. D. McMillan. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 30–38). The author describes tests on eleven white cast irons with silicon varying from 0·90% to 1·80%, to determine the effect of the silicon content on the time required to complete the first stage of graphitisation, *i.e.*, the graphitisation of excess cementite. It was found that the time required ranged from 24 hr. for the low-silicon irons to 3 hr. for the high-silicon irons. The number of graphite nodules was greater in the high-silicon irons, whereas prolonging the holding time decreased the number.

Graphitization Symposium—IV. Periodic Malleable Annealing Furnaces. W. R. Bean and W. R. Jaeschke. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 39–49). The authors describe direct-fired and muffle batch malleablising furnaces heated with hand-fired lump coal, pulverised coal and oil. Details are given of fuel costs, method of packing in boxes, stacking methods and temperature control.

Graphitization Symposium—V. Malleable Annealing in the Dressler or Tunnel-Type Kiln. R. J. Anderson. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 50–66). The author describes a Dressler car-type malleablising furnace at the works of the Belle City Malleable Iron Co. This furnace has a rail-track down the centre and a refractory muffle down each side; it is sufficiently long to accommodate 62 cars each loaded with 4½–5 tons of castings. The cars are pushed with a hydraulic ram at the loading end at the rate of 12 per day, each car taking 124 hr. to pass through the tunnel. In periods of low production the very long furnace was found to be uneconomic; an opening was therefore constructed half-way along, with hinged doors that could be controlled from outside the furnace. With this arrangement one half of the furnace could be heated by itself, and this was found both practical and economical. Particulars are given of the temperatures maintained, methods of control and costs.

Graphitization Symposium—VI. Electric Furnace Annealing of Malleable Iron. R. M. Cherry. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 67–80). The author describes and discusses the advantages and disadvantages of electrically heated pusher and roller-hearth malleablising furnaces. From the point of view of current consumption per ton of castings the roller-hearth furnaces are slightly superior, and the maintenance cost of trays and rails for the latter type of furnace is also somewhat lower.

Graphitization Symposium—VII. Graphitization of Arrested Anneal Malleable Iron. D. P. Forbes. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 81–94). The author discusses two methods of graphitising white cast iron; in one the malleablising treatment is "arrested" while some of the

combined carbon remains in solution in the matrix, and in the other, the iron is fully malleablised so that practically no combined carbon remains in the matrix, and it is then given a second treatment to bring the temper carbon back into solution in the matrix, where it is retained by quenching. Details are given of the time-temperature cycles required in the two forms of treatment and of the physical properties of the castings produced. Such iron, often called "pearlitic malleable," is of higher strength and wear-resistance, but is slightly less ductile than normal malleable iron.

Graphitization Symposium—VIII. Atmospheres and the Annealing of Malleable Iron. R. J. Cowen. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 95–106). The author discusses the effects of surface decarburisation on the malleablising process. Surface decarburisation must be prevented during the first stage of the process because this considerably increases the time required for the second stage of malleablising. After the iron has reached full temperature, graphitisation of the combined carbon proceeds so rapidly that the amount of carbon in the matrix is considerably reduced in a comparatively short time. If the castings are surrounded in a protective atmosphere rich in hydrocarbons there will come a time when it will cease to be protective in the sense of preventing the loss of carbon from the metal, and will begin to recarburise the surface. If such an atmosphere be maintained throughout the entire first stage of the malleablising treatment, the surface of the casting will be found to have a sheath of carburised metal of a form that it is almost impossible to graphitise. In practice this difficulty can be got over by discontinuing the flow of gas after the metal has been at the maximum temperature for about 2 hr. When this is done the time required for the first stage is reduced much below the normal periods, and the metal will respond much more readily to the second stage of the treatment.

Some generators for preparing special atmospheres for malleablising furnaces are described.

Graphitization Symposium—IX. Some Effects of Hydrogen on the Time of Malleablization. C. H. Lorig and M. L. Samuels. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 107–125). *See* Journ. I. and S.I., 1942, No. II., p. 167 A.

The Production of Steel Castings. F. W. Rowe. (Journal of the Institution of Production Engineers, 1942, vol. 21, Dec., pp. 469–483). The author gives an account of the production of steel castings, describing in turn moulding methods, the provision of runners and feeder-heads, design to eliminate shrinkage cavities, closing the moulds, shot-blasting and dressing, heat treatment, metallurgical control and methods of testing.

Theory of the Solidification of Castings. N. Chworinoff. (Iron and Steel Institute, 1943, Translation Series, No. 117). An English translation is presented of a paper in which formulæ are developed for calculating the rate and manner of the solidification of steel

castings of various shapes. The original appeared in Giesserei, 1940, vol. 27, May 17, pp. 176–186; May 31, pp. 201–208; June 14, pp. 222–225 (*see* Journ. I. and S.I., 1941, No. II., p. 116 A).

The Refractoriness and Evaluation of Mould Materials. W. Vaska. (Giesserei, 1942, vol. 29, Sept. 4, pp. 311–313). The author discusses the behaviour of moulding and core sands in contact with molten and hot solid metals. The fusion point of grains of quartz sand is about 1750° C., but in contact with iron oxide (Fe_3O_4) the fusion point is considerably lower. As this oxide is formed when molten iron and steel are poured, the small quartz grains on the mould and core surfaces fuse on to the casting. The sticking of sand to castings is not caused by the alumina in the binding clay. No sand is found to burn on to a steel casting if the quartz sand contains a clay of low refractoriness (1080° C.) with alkalies present. Sand will, however, burn on to a grey iron casting, although the temperature may be 300° C. less than that of molten steel. The same applies to a sand containing cement as a binder. A steel containing carbon 0·32%, manganese 0·70% and silicon 0·31% was teemed through a fireclay tube which melted away, the resulting slag was analysed and found to contain more MnO than FeO in spite of the low manganese in the steel. In another test with a 2%-manganese steel, the resulting slag contained MnO 20·80% and FeO only 1·44%. It does not follow that the resistance of a material to slag attack is greater with increasing refractoriness.

Unusual Patterns and Special Equipment for War Production. W. C. Perry. (Institute of British Foundrymen: Foundry Trade Journal, 1942, vol. 68, Dec. 31, pp. 381–382). The author discusses the making of unusual patterns of wood and of metal, in particular those for tank tracks.

Some Technical Aspects of Foundry Cores. H. A. Stephens. (Institute of Australian Foundrymen: Commonwealth of Australia, Council for Scientific and Industrial Research, 1942, Industrial Chemistry Circular No. 1). The author reviews methods of making cores, discussing in particular the different types of binders and equipment for drying and testing cores. Experiments have shown that the cost per lb. for drying cores is less in an oven filled to capacity than in an oven partly full. It is therefore necessary to consider carefully the size of the oven that will be needed, and if the oven space is too large, it may be more economical to allow cores to accumulate until the oven is nearly full before heating up. A considerable amount of energy is used in heating driers and core-plates so that the size of these should be kept down to a minimum.

Chemical Phenomena in the Drying of Cores. F. Roll and Annemarie Riess. (Giesserei, 1942, vol. 29, Sept. 18, pp. 320–326). The authors studied the behaviour of core-sands and binders when drying cores at 20°, at 20–120° and at over 120° C. The binders were classified in four groups, consisting of: (*a*) Linseed oil, wood oil and train oil; (*b*) sulphite lye and molasses; (*c*) starch and

dextrine ; and (*d*) stearine pitch and sulphate pitch. When drying cores with oil-binders of group (*a*), practically no distillation takes place at under 100° C. At higher temperatures the very large surface area of the sand grains has a marked effect on the distillation. On distilling the binder alone there might be as much as 60% distillate, but on distilling a core-sand while excluding the air there is 30% distillate and, in air, only 20%. The different behaviour of the four groups of binders shows that, for proper drying, the heat treatment must be planned to a definite schedule having regard to the stages at which air, gases and moisture are driven off, and the principles of colloid chemistry must be taken into account.

PRODUCTION OF STEEL

(Continued from pp. 80 A–84 A)

The Metallurgy of the Bessemer Process. Theory and Practice. H. Wentrup. (Iron and Steel Institute, 1943, Translation Series No. 121). This is an English translation of a paper which was published in Stahl und Eisen, 1942, vol. 62, Sept. 3, pp. 749–756. (*See* p. 9 A).

The Basic Open-Hearth Process To-Day. Part IV. Pitside Practice, Instruments and Fuel. W. Geary. (Metallurgia, 1942, vol. 27, Nov., pp. 23–27 ; Dec., pp. 77–79). Conclusion of a series of articles (*see* p. 47 A). The author discusses in turn, ladles, stoppers and nozzles, teeming, ingot moulds and instruments for controlling open-hearth furnaces. Ladle capacity can be increased by careful reduction of the thickness of the lining in those places where least wear takes place ; an increase of up to 15 tons in the capacity of a large ladle can be obtained in this way. Much attention is now given to the drying of prepared stoppers, and a type of oven is recommended with a stopper holder which revolves one notch of a non-return ratchet each time a stopper is inserted, thus making it impossible for a stopper to be withdrawn before the predetermined drying time has elapsed. A cinematograph film taken at high speed and projected at slow speed has revealed that there is no swirling action in the stream of steel leaving a ladle. Undue emphasis has been laid on the need for very small nozzles to ensure slow teeming and avoid cracking ; if top pouring is used some splashing of the mould walls will take place, but the more rapid rise of metal which takes place when faster teeming is employed causes most of these splashes to be washed off and redissolved. Tar is most commonly used for coating ingot moulds, and the mould temperature when tar is applied should be such that the tar dries off, leaving a glaze. Any attempt to increase instrumentation will be of little avail unless adequate provision for continuous maintenance under melting-shop

conditions is made. In discussing the Schofield quick-immersion thermocouple, the author points out that by taking a number of simultaneous readings with this and a disappearing-filament optical pyrometer it has been possible to correct the emissivity factors for a number of steels, and thus to increase the accuracy of determinations made with the latter instrument. Data on the use of producer gas, mixed gas (blast-furnace gas and coke-oven gas) and "three-gas" (mixed gas plus producer gas) are presented. Producer gas is used for heating about two-thirds of the steel furnaces in Great Britain. The producers should be worked not only with the object of making gas of high calorific value, but also so as to carry the maximum amount of tarry matter into the furnaces.

Basic Open-Hearth Cold Metal Practice. S. W. Pearson. (Iron and Steel, 1942, vol. 16, Dec. 17, pp. 113–116). The author discusses the charging and working of basic open-hearth furnaces using cold metal charges. With regard to the technique for adding iron oxide, if 3 or 4 tons of cold, and perhaps wet, oxide are plunged quickly into a bath with a fluid slag at perhaps 1500° C., there is bound to be a violent physical reaction, and an overflow of slag is likely to occur, but if the slag surface is temporarily chilled back, much of the oxide will lie upon this partially solidified surface, and only a small proportion will break the crust and react. In the meantime the balance of the oxide will have heated up appreciably, tending to attain as high a temperature as the slag, and no violent reaction will occur.

Application and Control of Capacitors on Multi-Phase Loads. W. A. Smiley. (Iron and Steel Engineer, 1942, vol. 19, Oct., pp. 26–33). The author explains how plant electric-power conditions were improved at a steelworks by the use of novel transformer connections and capacitors.

The Maintenance and Standardisation of Electrical Equipment at Iron and Steel Works. M. Hernberg. (Jernkontorets Annaler, 1942, vol. 126, No. 7, pp. 255–280). (In Swedish). The author discusses and makes recommendations on the planning, installation and maintenance of electrical equipment in an iron and steel works; in the second part of the paper he deals with the possibility of increased standardisation.

Brushes and Brush Application. W. H. Beyerle. (Iron and Steel Engineer, 1942, vol. 19, Oct., pp. 40–43). The author makes recommendations on the maintenance of brushes for electric motors.

Alloy Scrap in Steelmaking. C. H. Herty, jun. (American Society of Mechanical Engineers: Metals and Alloys, 1942, vol. 16, Aug., pp. 253–254). The importance of reclaiming at all stages of manufacture as high a proportion as possible of alloy steel scrap is stressed. The use of this scrap presents two problems: (1) Obtaining the scrap in proper form for charging; and (2) determining whether the scrap charged contains any elements not wanted in the heat. The first problem is dealt with by some form of crushing,

briquetting or baling. The second necessitates the active co-operation of users of the alloy steels to organise in their shops the careful segregation of different kinds of scrap.

The Melting Together of Bushy Steel Turnings in a Furnace. F. Köhler. (Stahl und Eisen, 1942, vol. 62, Oct. 29, pp. 921–922). The author describes a method of reducing the bulk of bushy steel turnings which has been developed and patented by the Dortmund-Hoerder Hüttenverein. The process is based on the fact that steel turnings will burn without the addition of a fuel. A vertical cylindrical furnace with a conical bottom is required; the upper part is lined with refractory bricks, and the lower part with a rammed refractory. A circulation pipe for water-cooling is incorporated in the lining round the hottest zone. The furnace stands on four columns, about 4 ft. high, under which a conveyor belt with cast-iron trays moves to carry away the product from the mouth of the cone. Ignition is commenced with a small wood or coke fire, after which no more fuel is required. The furnace requires almost continuous feeding with turnings, which can be done by a crane and grab, and it makes no difference whether the turnings are clean, oily or rusty. The partial burning of the lowest layer of turnings develops so much heat that a certain proportion melts without burning and the remainder break up into shorter lengths. The product leaving the bottom of the furnace consists of metallic iron with a small portion of oxide and a large proportion of broken-up turnings. An average sample of the product contains 90% of metallic iron and 10% of ferrosoferric oxide. The throughput of the furnace is about the same as the rate at which turnings can be unloaded from a railway truck with a steam crane. Two furnaces of this type have been in successful use for over a year.

Swarf Washing and Oil-Recovery Plant. (Engineering, 1943, vol. 155, Jan. 15, pp. 46–47). A description is given of a plant for removing and recovering oil from large quantities of turnings. The principle adopted is the washing of the swarf by sprays of water as it is transported on a conveyor, and recovering the oil from the wash-water by a combination of settling and centrifuging. The plant in question will clean 10 tons of swarf per day, from which as much as 30 gallons of oil per ton may be recovered.

Production of Metallic Calcium. (Metal Treatment, 1942, vol. 9, Winter Issue, pp. 193–195). A brief account is given of a method developed in the United States for producing calcium by the electrolysis of calcium chloride. The forms in which calcium is available and its application as a deoxidiser for steels are also described.

Determination of Inclusions. A. G. Arend. (British Steelmaker, 1943, vol. 9, Jan., pp. 32–35). The author describes a modification of Fitterer's electrolytic method of determining inclusions in steel. In this method, by electrolysing selected samples of steel, the iron content can be made to migrate to the anode, while inclusions in the form of oxides, sulphides, slag particles, &c.,

remain as an anode sludge. In the improved method almost the entire sample is consumed; this is done by preparing the sample in round or elliptic "two-bar" form. The electrolyte consists of 3% ferrous sulphate crystals and 1% sodium chloride dissolved in distilled water. An artificial-silk product is used for the dialysing bags and, instead of applying 1 amp. per 50-g. sample, five times this current can be substituted depending upon the A.C./D.C. ratio and the frequency of the former. The electrolysis is carried out in a copper tank which serves as the cathode for six samples. The samples become ionised with two positive charges, and the iron constituent passes rapidly into solution; in so doing the electrolyte passes through the walls of the bag, leaving behind the anode sludge which represents the inclusions contained in the sample.

FORGING, STAMPING AND DRAWING

(Continued from p. 84 A)

The Development of Forging Practice in Australia. W. Noad. (Australian Institute of Metals: Australasian Engineer, 1942, vol. 42, Oct. 7, pp. 9–11, 41–43). The author discusses the development of forging practice in Australia, describing and illustrating many of the steam hammers and hydraulic presses used.

Pressing Heavy Steel Shapes. E. F. Cone. (Metals and Alloys, 1942, vol. 16, Aug., pp. 232–237). The author describes some heavy pressing operations at the works of Lukens Steel Co., Coatsville. These include: (*a*) The pressing of chamber heads 50 in. high, 59 in. wide, 22¾ in. deep and 3½ in. thick; (*b*) combustion chamber heads for marine boilers; (*c*) brake-drums pressed from flat discs 79 in. in dia. × 1½ in. thick; and (*d*) firebox parts.

Maintenance of Hydraulic Equipment. G. C. Pfeffer. (Iron and Steel Engineer, 1942, vol. 19, Oct., pp. 43–44). The author makes recommendations on the maintenance of hydraulic systems with the object of reducing or preventing water hammer; these relate to the fitting of shock-valves and air-bottles.

Electric Patenting of Wire. J. P. Zur. (Wire and Wire Products, 1942, vol. 17, Oct., pp. 552–560). The author describes the patenting of steel wire by a method in which the wire is heated by its own resistance to an electric current passed through it. The microstructures and properties of electrically patented and furnace-patented wires of 0·47% and 0·62% carbon steels are compared. After electric patenting, the pickling time necessary for cleaning was only about half that required after furnace patenting. The tensile strength, elongation and fatigue strength were greater for the electrically patented wire. The electric treatment also has the following advantages: (1) There is no surface decarburisation and

practically no scale, even without using protective atmospheres; (2) much finer grain structures can be produced; (3) the patenting treatment is more rapid; (3) the heating and cooling cycles can be controlled very accurately; and (4) the wire is quenched on a rising temperature.

Scheduling and Planning the Wire Mill for War Production. L. D. Seymour. (Wire and Wire Products, 1942, vol. 17, Oct., pp. 523–531). The author describes a system of production control now operating successfully at a large Canadian wire mill doing jobbing work. Specimens of the forms used in the various departments are reproduced.

ROLLING-MILL PRACTICE

(Continued from pp. 53 A–54 A)

Maintenance of Ball and Roller Bearings. A. A. Van Pelt. (Iron and Steel Engineer, 1942, vol. 19, Oct., pp. 65–69). The author makes recommendations for the storing, cleaning and fitting of ball and roller bearings for electric motors, with particular reference to the equipment of the bearing-maintenance department.

New Developments in Lubricants for Steel Plants. M. Reswick. (Iron and Steel Engineer, 1942, vol. 19, Oct., pp. 55–61). The author discusses the properties of extreme-pressure oil and greases for rolling-mill bearings and presents data on lubricants containing lead oleate and lead naphthenate.

Roll More Tons. IV. Channel Calibrations. A. E. Lendl. (Iron and Steel, 1942, vol. 16, Nov., pp. 37–40, 45). Continuation of a series of articles (*see* p. 54 A). In this part the author examines the calibration of a pass for a channel section. The calculations of the lateral spread give valuable information as to where alterations could be made to reduce the wear on the surfaces of the grooves so as to make the rolling smooth and economical.

PYROMETRY

(Continued from pp. 54 A–55 A)

Automatic Time-Temperature Control in Heat Treating. (Iron Age, 1942, vol. 150, Nov. 5, pp. 54–55). A detailed description is given of an automatic temperature recording and controlling instrument with an example of its operation to control a heat-treatment furnace at a given temperature cycle.

Temperature Measuring Instruments. A. Linford. (Engineering and Boiler House Review, 1942, vol. 56, Dec., pp. 210–217; 1943, vol. 57, Jan., pp. 2–8). The author reviews the design and

application of temperature-measuring instruments, dividing them into three classes : (1) Those operated by a change in length of a solid, or volume or pressure of a liquid ; (2) those operated by a change in some electrical function caused by a change in temperature ; and (3) those based on principles of radiation.

Graphitization Symposium—X. Temperature Control of Graphitizing Furnaces. J. H. Lansing. (Transactions of the American Foundrymen's Association, 1942, vol. 50, July, pp. 126–132). A brief explanation of the principle of temperature measurement by means of thermocouples is given and the type of instrument for controlling the temperatures of malleablising furnaces is described.

HEAT TREATMENT

(Continued from pp. 84 A–87 A)

The Training of the Young Metallurgist. D. G. P. Paterson. (Sheet Metal Industries, 1942, vol. 16, Oct., pp. 1489–1496 ; Nov., pp. 1657–1661, 1673 ; Dec., pp. 1845–1849). This is a continuation of Part V. of the series of articles (*see* Journ. I. and S.I., 1942, No. II., p. 221 A). This section deals principally with heat treatment. Some batch and continuous furnaces are described and illustrated, and explanations of annealing, bright-annealing and normalising are given, together with information on the composition and purpose of various heat-treatment furnace atmospheres. A number of heat-treatment installations for ferrous and non-ferrous metals is illustrated and described. The properties of austenitic corrosion-resisting steels are discussed and the principles of temperature-recording instruments are explained.

Heat Treatment and Machinability of S82 Gears. (Mechanical World, 1942, vol. 112, Dec. 18, pp. 579–580). The material covered by Air Ministry Specification S82 is a case-hardening alloy steel containing nickel 4·0–4·5%, chromium 1·0–1·5% and molybdenum 0·20–0·50%, which is used for highly stressed aircraft gearing. Because of its high alloy content it is one of the most difficult steels in which to obtain reasonable machinability at the various stages of manufacture. A banded structure in the steel gives particularly poor results in all machining operations, and especially in rough-machining prior to carburising. Details are given of two heat treatments, both of which have given good results. The second one, which is much shorter, is an austempering treatment consisting of heating the parts in an open furnace to 840° C., soaking for 1 hr., transferring the load to another furnace at 650° C., soaking for 1 hr. and cooling in air. This treatment breaks up the banded structure, refines the grain and results in a great improvement in the machinability and surface finish.

Flame Hardening with City Gas. Premixing Practice. R. F. Apter and H. W. Smith. (Machinist, 1942, vol. 86, Dec. 19, pp. 947–949). The authors compare flame-hardening using oxygen and acetylene or propane with the results obtained using air and town gas. With the latter, decarburisation and burning of the metal do not occur and the fact that most of the heat is transferred by radiation of the air-gas flame enables deeply recessed areas to be heated up and hardened. Suitable equipment for mixing the town gas and air is described.

"Purging" Controlled Atmosphere Furnaces. F. B. Leslie. (Metals and Alloys, 1942, vol. 16, Aug., pp. 241–245). To prevent the explosion of protective atmospheres rich in hydrogen or carbon monoxide when heat-treatment furnaces are brought up to temperature, it is usual to purge the air from the furnace while it is cool to bring the gas/air ratio well above the explosive range. In this paper an instrument is described which indicates when the purging is complete, and thus prevents the waste of gas which occurs when the operation is continued too long.

WELDING AND CUTTING

(Continued from pp. 88 A–89 A)

Development in Cast-Iron Welding Rods and Electrodes. R. J. Franklin. (Welding Journal, 1942, vol. 21, Oct., pp. 698–699). The author discusses the influence of silicon, phosphorus, nickel and copper in cast-iron welding rods on the properties of the welds obtained. The generally accepted silicon content of 3% in rods with 3·30–3·40% of total carbon is thought to be too high, for tests with rods containing 2·20% of silicon showed that neither the hardness nor the machinability were adversely affected. Decreasing the phosphorus content of the low silicon rod from 0·75% to 0·20% was not detrimental to the fluidity. In the case of the other elements found to be successful when used in combination with graphite, it is probable that the graphite plays the major rôle in inoculation, and that the metallic elements condition the weld metal by producing the necessary fluidity, thus permitting the inoculation by the graphite to occur. Nickel seems to be more or less neutral in conditioning the metal, although it can be used as an alloy. Copper will produce the desired characteristics, but it seems to be too sensitive at the fusion zone when welding certain low-carbon, low-silicon types of iron.

Welding Stainless Steel. A. J. T. Eyles. (Mechanical World, 1942, vol. 112, Dec. 11, pp. 551–555). The author describes the technique for oxy-acetylene and electric welding stainless steel of different thickness. The different expansions of the various

steels must be taken into account; a straight chromium steel has a coefficient of expansion about 10% less than that of mild steel, whilst that of the chromium-nickel types is about 50% greater. In resistance welding, the mechanical pressure applied may be 75–100% above that used in welding ordinary steel. Several examples of welded stainless-steel equipment are illustrated.

Welding Nickel, Monel and Inconel Clad Steels. W. G. Theisinger. (Iron and Steel Engineer, 1942, vol. 19, Oct., pp. 75–80). The author describes the technique for electric welding steel plates clad with nickel, Monel metal or Inconel with special reference to the fabrication of railway tank wagons for conveying caustic soda and other chemicals.

Electric Arc Welding of Structures and Plant in the Steel Industry. J. Wright. (Journal of the West of Scotland Iron and Steel Institute, 1942, vol. 50, Part I., pp. 3–6). The author describes and illustrates some examples of special electric welding work at a steelworks. The examples include a stanchion portal to support two crane gantries at right angles to each other, a large tapering bend of $\frac{3}{8}$-in. plate 7 ft. 3 in. in dia. at one end and 5 ft. in dia. at the other, and the casing and roller supports for an electric tilting furnace.

How to Select Arc Welding Electrodes. C. H. Jennings. (Iron Age, 1942, vol. 150, Oct. 15, pp. 42–47). The author discusses the characteristics of some of the low carbon steel welding electrodes which are included in the Tentative Specifications for Iron and Steel Arc Welding Electrodes prepared by the American Society for Testing Materials and the American Welding Society.

Memoranda on the Inspection and Control of Quality of Spot Welds in Mild Steel. (Ministry of Supply, 1942, Welding Memorandum No. 8). The object of this Memorandum is to provide a summary of the factors which affect the quality of spot-welds, and to suggest methods of controlling and inspecting the quality.

The Inspection of Welding. (Journal of the Institution of Production Engineers, 1942, vol. 21, Dec., pp. 492–516). This paper constitutes the First Report of the Welding Sub-Committee of the Institution of Production Engineers; in it an account is given of investigations of the permissible increase in the diameter of the electrode tip for spot welding before having to change it. It was thought that the permissible increases given in Welding Memoranda No. 8 of the Ministry of Supply (*see* preceding abstract) were unduly restricted. From experimental work on clean 20 S.W.G. mild-steel sheet it was concluded that: (1) A truncated cone with an included angle of 120° can be recommended as a tip contour; and (2) although an increase of up to 103% in the tip diameter was recorded without severe falling off in weld strength or consistency, it appears necessary to limit the number of welds made under the stated conditions to the point at which surface appearance commences to deteriorate rapidly.

The Spot Welding of N.A.X. High-Tensile Steel. C. R. Schroder. (Welding Journal, 1942, vol. 21, Oct., pp. 690–694). In this paper the author discusses the results obtained in an earlier investigation by himself and W. F. Hess on the properties of spot welds in a low-alloy high-tensile steel sheet (*see* Journ. I. and S.I., 1942, No. II., p. 144 A). The chisel test is a practical workshop method of determining the proper magnitude of the heat-treatment current. Hardness tests at the centre of weld cross-sections for a series of welds with progressively increasing heat-treatment current enable the optimum current value to be accurately determined. The general procedure and method used could probably be applied to improve greatly the quality of spot welds in all types of low-alloy high-tensile and deep-hardening steels.

Machine Flame Cutting. E. H. Witt and A. Watson. (Australian Welding Institute: Australasian Engineer, 1942, vol. 42, Sept. 7, pp. 24a–25). The authors describe some of the oxy-acetylene cutting machines used in Australia and make recommendations on their maintenance.

PROPERTIES AND TESTS

(Continued from pp. 94 A–105 A)

The Relationship between the Chemical Composition and the Mechanical Properties of Cast Iron. G. Brinkmann and P. Tobias. (Giesserei, 1942, vol. 29, Sept. 18, pp. 317–320). The authors discuss formulæ which express the degree of carbon saturation in cast iron in terms of the carbon and silicon contents, and report the results of tests on samples from 100 melts, the object of which was to establish how the manganese and phosphorus contents affected this relationship. The irons tested covered analyses within the following limits: Carbon 2·6–3·8%, silicon 0·95–3·5%, manganese 0·14–1·34% and phosphorus 0·12–0·91%. From the results obtained the formula of H. Jass, namely:

$$\text{Degree of carbon saturation} = \frac{\%\ \mathrm{C}}{4{\cdot}23 - 0{\cdot}312\ \mathrm{Si}},$$

should be amended to:

$$\frac{\%\ \mathrm{C}}{4{\cdot}23 - 0{\cdot}312\ \mathrm{Si} - 0{\cdot}33\ \mathrm{P} + 0{\cdot}066\ \mathrm{Mn}},$$

so as to take the effect of phosphorus and manganese into account. The tensile strength and hardness are in straight-line relationship with this corrected saturation value.

A Killed Manganese-Phosphorus Basic-Bessemer Steel with a Minimum Tensile Strength of 46 kg. per sq. mm. R. Wasmuht, C. Salzmann and F. Bischof. (Stahl und Eisen, 1942, vol. 62, Nov. 12, pp. 963–968). The authors describe an investigation of

the properties of an aluminium-killed steel, intended for large structural work, having a minimum tensile strength of 46 kg. per sq. mm. and containing carbon 0·13% max., manganese 1·0% max. and phosphorus 0·17% max. The segregation, structure, mechanical properties and weldability were studied using 5-cwt. and 4-ton ingots and material rolled from them. The strength at 400° C. was found to be adequate. The notched-bar toughness at − 50° C. was low. The fatigue strength of plain and notched specimens was considerably greater than that of steel St 37, but less than that of steel St 52. Favourable results were obtained in the bend test on beads on plates 30-mm. thick. In general, it was considered that this structural steel could be successfully introduced as having properties between those of the German structural steels St 37 and St 52.

Effect of Cold-Rolling on the Properties of 18/8 Stainless Steel. W. Puzicha. (Stahl und Eisen, 1942, vol. 62, Oct. 29, pp. 920–921). The author reports the results of an investigation of the effects of cold-rolling on the tensile strength and magnetic properties of 18/8 stainless steel strip containing carbon 0·05%, silicon 0·37% and manganese 0·66%. It was found that when the reduction was effected in one pass, the magnetic saturation was much lower than if the same total reduction was obtained in a number of successive passes. The increase in tensile strength was only slightly less after one pass than after several passes. If the rolls were heated so that the strip temperature was raised to 200° C., the increase in tensile strength was less marked than after rolling at room temperature. The magnetic saturation values after rolling in heated rolls dropped in some instances to less than 1 c.g.s. unit per g.

Effect of Cold-Rolling and Annealing on the Watt Loss of Dynamo and Transformer Strip Steel. A. Pomp and H. Wübbenhorst. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 15, pp. 279–292). The authors studied the effect of the degree of cold-deformation and of annealing temperature and time on the watt loss of three basic open-hearth steels. (*See* Journ. I. and S.I., 1942, No. II., p. 120 A).

Deformability at Low Temperatures. A. Krisch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 14, pp. 267–277). The author describes an investigation of the plastic deforming properties, under conditions of multi-axial stress, of five unalloyed and five alloy steels at room temperature and at − 183° C. The five straight carbon steels contained carbon in the range 0·02–0·77%; there were also four chromium-molybdenum steels and one chromium-molybdenum-vanadium steel. When using a notched specimen it was difficult to measure the deformation in tension, as the gauge length had to be short; to overcome this difficulty notches were not used, but specimens were turned with a collar in the centre; this produced a tri-axial stress condition in tensile tests. Bend tests on notched and plain specimens as well as

impact tests were carried out. With the alloy steels the increase in the elastic limit and the tensile strength of plain specimens at low temperatures were not so great as with the softer carbon steels. The reduction in area at $-183°$ C. was about two-thirds of that at $+20°$ C. The reduction in plastic deformation at low temperatures was much less for the alloy steels than for the carbon steels. The behaviour of specimens with collars was quite different; with a 0·23% carbon steel there was a very slight increase in the tensile strength, whereas there was a reduction in elongation from 19·3% for the plain specimen to 15·3% for the specimen with a collar. The reduction of area was not affected by the form of specimen. Contrary to the carbon steels, alloy steels were much less sensitive at low temperatures to a change in specimen shape which caused uneven stress distribution; it is probable that these alloy steels offer a better resistance to unforeseen stresses, *e.g.*, a bending moment caused by inaccurate fitting, because they retain, even at low temperatures, their plastic-deformation capacity.

In general, the various tests revealed that the capacity for plastic deformation of the steels under multi-axial stresses varies greatly.

Statistical Investigations on the Causes of Fracture in Tyres and Rails. A. Pusch. (Stahl und Eisen, 1942, vol. 62, Dec. 3, pp. 1022–1033). The author reports on an analysis of the type and causes of fracture of over 550 cases of broken tyres and of 1300 broken rails, undertaken for the German State Railways. In locomotive and tender tyres, 57% of the fractures were due to fatigue, whilst this accounted for only 13% of those occurring in wagon tyres, which were of softer steel. The life of a locomotive tyre which fractured because of an internal defect was much shorter than of a tyre fractured by a fatigue crack commencing at the surface. About half of the rail fractures were due to internal defects, mainly cavities; fractures in the flat bottom and stress cracks are next in importance as causes, and after them come corrosion and traffic conditions. The life of fractured rails varied between 1 and 20 years, frequency curves indicating a peak at between 1 and 4 years; this peak lies between 5 and 8 years for rails fractured as a result of horizontal cavities in the head and corrosion cracks. Fractures due to cavities occurred most frequently in old rails with a tensile strength below 70 kg. per sq. mm. Stress cracking, on the other hand, became frequent enough to be noticeable at a minimum tensile strength of 80 kg. per sq. mm. and, with the rails of about 100 kg. per sq. mm. min. tensile strength, this was responsible for about 90% of the failures. The phosphorus and sulphur contents of the newer rails were less than those of the older ones, but neither this nor the degree of segregation appeared to influence the failures.

The Fatigue Testing of Cast Iron and Malleable Cast Iron. M. Hempel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung: Giesserei, 1942, vol. 29, Sept. 4, pp. 302–311). The author reviews some results obtained in recent investigations of the

fatigue strength of cast iron and malleable cast iron. He finds that, in spite of the erratic behaviour of cast iron as compared with steel, and although it has less elongation and does not follow Hooke's law, it is an excellent material to use where a high damping capacity and a low notch-sensitivity are required. The effects of various factors, such as the value of the mean stress and the character of the stress reversals, are discussed.

Hardness Testing of Heat-Treated Forgings. B. Thomas. (Metallurgia, 1942, vol. 27, Nov., pp. 28–30). The author discusses methods of testing the hardness of heat-treated forgings. He considers that testing machines of low loading capacity are unsuitable for rough forgings of considerable weight, but if such machines are the only ones available, the mean of at least three readings should be obtained. The manufacturer and the receiver should have some agreed arrangement regarding the use of similar testing methods.

Surface Finish of Journals. R. W. Dayton, H. R. Nelson and L. H. Milligan. (Mechanical Engineering, 1942, vol. 64, Oct., pp. 718–726). The authors describe tests to study how the surface finish of journals affect the running-in, the friction and the seizure of bearings. Profilographs of the surface finish were taken before and after the tests. Fine finishes were studied, the roughest having a profilometer reading of only 10 micro-inches. A fairly good correlation was found between the load required to cause seizure and the product of the profilometer readings taken in the axial and circumferential directions. The surfaces with the highest product had the greatest tendency to seizure. This was approximately true irrespective of the finishing methods employed; sand-papered surfaces had rather better than average seizure resistance and loose-abrasive-lapped surfaces rather poorer than average seizure resistance. During wearing-in, an extremely minute smoothing of the topmost part of the surface roughnesses took place, and this considerably changed the frictional characteristics.

Steel Division Issues First Report on Magnetic Powder Testing. (American Foundryman, 1942, vol. 4, Oct., pp. 25–29). This constitutes the First Report of the Committee on Magnetic Powder Testing appointed by the Steel Division of the American Foundrymen's Association. A number of definitions of magnetic phenomena are given first and the principles of magnetic-powder testing are explained in simple language. The wet and dry methods of applying powders to surfaces to be tested are described with some illustrated examples.

Heat Resisting Alloys. T. G. Beament. (American Society for Metals: Canadian Metals and Metallurgical Industries, 1942, vol. 5, Oct., pp. 292–295). The author discusses the factors to be considered in selecting heat-resisting alloys in the design of plant which is to operate at high temperatures. Stresses set up by temperature fluctuations cause more failures in the general run of high temperature mechanisms than all other causes combined;

allowance must therefore be made for dimensional variations which are many times as great as those encountered in ordinary structural engineering. Structures to operate at high temperatures should, where possible, be broken up into small units, all of which being free to expand and contract within their own limits; this is especially true of such parts as rail assemblies and trays.

Thermo-Electric Power of Very Pure Iron between 20° and 230° C. F. C. Thompson and N. C. Saha. (Iron and Steel Institute, 1943, this Journal, Section I.). The thermo-electric power of very pure iron has been accurately measured in the temperature range from 20° C. to 230° C. No abnormalities which clearly exceed the experimental error have been noticed. The effects of such factors as the presence of hydrogen and cold-work have also been investigated, without any discrepancies being observed. The results tend to endorse the view, put forward by Sykes and Jones (*see* Journ. I. and S.I., 1939, No. I., p. 435 P), that the abnormalities in the mechanical properties of iron and its alloys are not reproduced in its more definitely physical properties.

The Influence of Temperature on the Modulus of Elasticity of Some Plain Carbon and Alloy Steels. G. C. Seager and F. C. Thompson. (Iron and Steel Institute, 1943, this Journal, Section I.). The variation of Young's modulus with temperature has been measured for a series of steels, both plain carbon and alloyed, using an interferometer of high sensitivity. It is shown that the curves are not smooth but have abnormalities which just exceed the experimental error.

The Rationalisation of Special and Alloy Steels to Meet War-time Needs. W. H. Hatfield. (Sheffield Metallurgical Association: Iron and Steel, 1942, vol. 16, Dec., pp. 66–77). **Special Steels and the Conservation of Alloys.** W. H. Hatfield. (Metal Treatment, 1942, vol. 9, Winter Issue, pp. 181–186). In the first part of the paper the author presents and discusses data on the imports during 1937 of the United Kingdom, the United States, Germany, Sweden, Belgium and Luxemburg of essential materials for special and alloy steel production. He then describes the work of the Technical Advisory Committee which dealt with alloy steel production and the rationalisation of steel specifications. The author considered that the requirements for all rolled products could be supplied by not more than seven different steels; the first three of these to contain: (1) Carbon 0·30–0·35% with manganese 0·70–0·80%; (2) carbon 0·70–0·80% with manganese 0·40–0·45%; and (3) carbon 0·35–0·45% with manganese 1·6–1·8%. The remaining four to be high-tensile steels, as follows: (4) Manganese-molybdenum steel; (5) 1·5%-nickel, 1%-chromium steel containing molybdenum; (6) 2·5%-nickel, 0·7%-chromium steel high in molybdenum; and (7) 4%-nickel, 1·25%-chromium steel containing molybdenum. Steel No. 7 is intended for the small amount of steel of large section required with over 100 tons per sq. in. tensile strength. The author urged that, for war purposes, properly hardened and tempered

carbon steels should be used to a far greater extent than they had been; he presented comprehensive data on the properties and microstructures of these steels which proved that they could be applied over a wide field.

NE (National Emergency) Alloy Steels. (Steel, 1942, vol. 111, Nov. 9, pp. 96–108). Several series of curves are presented showing the results of end-quench hardenability tests on the low-alloy National Emergency Steels NE 9500 and NE 9600.

Alloy Cast Iron. J. E. Hurst (Journal of the Birmingham Metallurgical Society, 1942, vol. 22, Sept., pp. 55–66). The author describes the present position in the development of alloy cast iron, giving two examples of its applications which demonstrate the use of the higher attributes of the strength properties. These examples are piston rings and valve-seat inserts. The classification of cast irons in British Standard No. 786 and the heat treatment of cast iron are discussed. The tempering of quench-hardened specimens is accompanied by a recovery in the tensile strength, and this recovery increases uniformly with increasing tempering temperature until a maximum is reached; the maximum strength recovered is substantially greater than the "as cast" value. The general characteristics of martensitic and austenitic cast irons are briefly considered.

A Thought for Silicon-Manganese Steel. B. Thomas. (Metallurgia, 1942, vol. 27, Dec., pp. 74–75). The author presents and discusses data on the properties of British Standard Steels "En 45" and "En 46"; both of these contain silicon 1·50–2·00% and manganese 0·60–1·00%, the former with carbon 0·50–0·60% and the latter with carbon 0·33–0·50%. It is shown that for a given heat treatment these steels have strength properties superior to those of straight carbon steels with 0·50% or 0·80% of carbon, and they also have greater resistance to distortion with less risk of fracture.

Nitrogen as an Alloying Element in Cr-Ni-Steels. D. W. Rudorff. (Metallurgia, 1942, vol. 27, Dec., pp. 68–71). The author reviews the literature on the effect of nitrogen on the properties of chromium-nickel steels with special reference to the development in Germany of a number of stainless and heat-resisting steels in which much of the nickel content is replaced by nitrogen.

Reference Tables of Rapid Scrap-Identification Tests. (Metals and Alloys, 1942, vol. 16, Aug., pp. 264–266). Three tables are presented in which are compiled methods of testing and the indications obtained when making rapid identification tests on various scrap metals, including grey cast iron, austenitic nickel-iron, plain carbon steel, a wide range of alloy steels and a number of non-ferrous metals and alloys. The testing methods include visual examination, magnetic tests, lathe-chip test, blowpipe test, chemical drop reactions and spark tests.

Round Strand Galvanised Steel Wire Ropes for Shipping Purposes. (British Standards Institution, No. 365—1942).

Comparative Investigations of Ribbed Bars of High-Quality Steel

and Round Bars. N. Tengvik. (Teknisk Tidskrift, 1941, vol. 71, Dec. 13, pp. 525–533). (In Swedish). The author presents the results of mechanical tests of the strength of concrete beams reinforced with ribbed round bars of high-tensile steel of a type rolled at a Swedish rolling-mill and proposes a standard specification for such bars.

Austenitic Manganese Valve Steel. H. Cornelius. (Luftfahrtforschung: Metal Treatment, 1942, vol. 9, Winter Issue, pp. 191–192, 198). The properties of fifteen chromium-nickel steels with up to 8·86% of manganese were investigated. The specific gravity, wear under dry friction, nitriding-hardenability, thermal expansion, thermal conductivity and creep strength were tested to ascertain which of the alloys was most suitable for facing the exhaust valves of aero-engines. The range of composition recommended is: Carbon 0·42–0·52%, silicon 1·5–2·0%, manganese 3–5%, nickel 6–4·5%, chromium 17·5–18·5% and tungsten 0·9–1·3%.

Steels in German Aircraft. H. Sutton. (Sheffield Society of Engineers and Metallurgists: Iron and Steel, 1942, vol. 16, Dec. 17, pp. 99–112). The information in this paper is based on the work of the Aero-Components Sub-Committee of the Technical Advisory Committee on Steels, Ministry of Aircraft Production. The author presents the results of mechanical and metallurgical tests on components taken from German aircraft. Probably the most outstanding feature of the steel components is the very good ductility and impact values obtained in many of the high-strength steels with the use of very small quantities of alloy additions.

A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts. Section I. A Description of the Enemy Engines Examined. Section II. Crankshafts. Section III. Connecting Rods. Section IV. Gudgeon Pins and Wrist Pins. Section V. Cylinders and Cylinder Liners. Section VI. Inlet and Exhaust Valves. Section VII. Valve Springs. Section VIII. Gears. Section IX. Bearings. Section X. Camshafts and Airscrew Shafts. Section XI. Castings. (Metallurgia, 1942, vol. 26, Aug., pp. 129–136; Sept., pp. 164–173; Oct., pp. 205–212; vol. 27, Nov., pp. 12–21; Dec., pp. 51–58). This report constitutes a summary of data obtained in the metallurgical examination of German and Italian aircraft engine and airframe parts by the Aero-Components Sub-Committee of the Technical Advisory Committee on Steels, Ministry of Aircraft Production.

Bonding Low-Tin Bearings to Iron and Steel. (Iron Age, 1942, vol. 150, Nov. 5, pp. 51–53). With the very low tin content now permitted for bearing metals and the decrease in the lining thickness, the problem of obtaining a very strong bond between the lining and the cast-iron or steel backing piece has arisen. This has been met in the United States by thoroughly cleaning the backing piece and "tinning" it with an alloy called "Flo-Met'l," which is a solid solution of a tin-antimony compound in lead capable of dissolving up to 7% of iron. The lining alloy can then be cast on to the tinned surface.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 105 A–111 A)

Electrolytic Polishing and its Application for Preparing Microspecimens. E. Löwgren and G. Hildebrand. (Jernkontorets Annaler, 1942, vol. 126, No. 4, pp. 131–142). (In Swedish). The authors describe a modification of the electrolytic polishing technique of A. L. De Sy and H. Haemers (*see* Journ. I. and S.I., 1941, No. II., p. 29 A) which they developed to suit the laboratory requirements of Fagersta Bruks A/B. In the method described the specimen rests on the anode and is completely immersed in the electrolyte with the polished surface horizontal and facing the cathode. The advantages claimed for this procedure are: (1) No clamps are required to hold the specimen; (2) the "corner effect" is so slight as to be negligible so that the specimen can be examined for decarburisation or other surface phenomena; (3) a constant current strength can be maintained irrespective of the size of the specimen as long as it is smaller than the anode plate; and (4) increased polarisation is obtained by having the anode under the cathode. Some micrographs of the polished surfaces are reproduced and discussed.

Radium in Industrial Radiography. R. L. Durant. (Metal Treatment, 1942, vol. 9, Winter Issue, pp. 139–148). The author discusses the advantages and disadvantages of using gamma rays in industrial radiography and explains why they are superior to X-rays for certain applications such as steel castings above 3–4 in. in thickness. The technique for making gamma-ray exposures and developing films is described in detail. The sharpness of the image of a flaw depends on three variables: (1) The diameter of the source—the image becomes sharper as the diameter of the source decreases; (2) the distance of the flaw from the film—the image becomes sharper as this distance decreases; and (3) the distance of the source from the film—the image becomes sharper with increase in this distance. To train a foundry radiographer in the interpretation of radiographs he should be allowed to cut up, in the first year, samples of every pattern of casting radiographed and in which defects are suspected.

Trends in the Technique of Industrial Radiography. H. E. Seemann. (ASTM Bulletin, 1942, Mar., pp. 21–26: Engineer, 1942, vol. 174, Dec. 18, pp. 492–495). The author reviews the principal features of radiographic procedures for the examination of metals, dealing in turn with intensifying screens, the size of the focal spot, variable illumination, filtration, X-ray and gamma-ray films, and microradiography.

A Rapid X-Ray Diffraction Method. A. T. McCord. (Industrial and Engineering Chemistry, Analytical Edition, 1942, vol. 14, Oct., pp. 793–796). The author describes a technique for the rapid preparation of powder samples for X-ray diffraction work. The sample is formed into a rigid rod 3 mm. in dia., and is inserted in the camera to form one side of the defining slit. Under average conditions patterns are obtained which are sufficiently clear to identify crystalline powders, irrespective of their coefficients of absorption. An optimum set of conditions may be defined for any mixture of two or more substances so that analyses may be made with improved accuracy.

The Positions of the Carbon Atoms in Martensite. N. J. Petch. (Iron and Steel Institute, 1943, this Journal, Section I.). It has been found impossible to obtain direct evidence of the positions of the carbon atoms in martensite. Indirect evidence can, however, be obtained from the change in cell dimensions with carbon content and from the fact that the structure is tetragonal.

It is concluded that the carbon atoms are at the mid-points of the long edges of the martensite tetragonal cell and at the centres of the faces perpendicular to them. These positions are crystallographically equivalent. In them the carbon atoms are surrounded by octahedra of iron atoms. There is never enough carbon in solution for all these positions to be filled. This would require 2·0 carbon atoms per unit cell, whereas, with the observed maximum carbon content, there will be an average of only 0·16 per unit cell. The behaviour is as if, at the most, each position were one-twelfth filled.

The martensite structure is interesting because of its being tetragonal at all, and because the interstices utilised by the carbon atoms are not those which would normally be considered the largest.

ANALYSIS

(Continued from pp. 68 A–69 A)

Rapid Carbon Determination at Furnace of Remelted Alloy Steels. R. O. Kern. (American Foundryman, 1942, vol. 4, Sept., pp. 8–10). The author describes a method of rapidly determining the carbon content of low-alloy steel which has been successfully used at an American steel foundry during the refining of steel in an electric furnace. From the results of many tests a reference curve relating the Brinell hardness to the carbon content was prepared. Spoon samples from the furnace are killed with aluminium or ferro-silicon and water-quenched. The mean of three Brinell hardness readings is taken, and from this value the carbon content is read from the

curve. The method has been found very accurate in the 0·15–0·45% carbon range for steels low in nickel and chromium.

Determination of Carbon in Low-Carbon Iron and Steel. L. A. Wooten and W. G. Guldner. (Industrial and Engineering Chemistry, Analytical Edition, 1942, vol. 14, Oct., pp. 835–838). The authors describe an improved apparatus for the determination of carbon in iron by the low-pressure combustion method and its application to samples of very low carbon content. The method is inherently of very high sensitivity, but to exploit this it is necessary to exercise care in the purification of the oxygen and in the selection and conditioning of the combustion crucible.

Application of the Spectrograph in Steel Plants. C. C. Nitchie. (Steel, 1942, vol. 111, Nov. 9, pp. 82–84, 124, 125). The author gives a concise explanation of the principles of the spectrograph and describes its application for steelworks' analyses.

A Critical Consideration of Some Applications of the Spectrograph to Steelworks Analysis. H. T. Shirley and E. Elliott. (Iron and Steel Institute, 1943, this Journal, Section I.). Developments in the technique and application of spectrographic methods to quantitative analysis have been rapid in recent years. In regard to steel, F. G. Barker (Journ. I. and S.I., 1939, No. I., pp. 211 P–245 P) discussed and laid down a detailed procedure for the application of the spectrograph to low-alloy materials. The present authors have studied in considerable detail the application of such a method to routine steelworks' analysis.

It is pointed out that, at the present stage of development, errors in spectrographic analysis are often considerably greater than those of the alternative chemical procedure and possible advantages in speed or economy can only be exploited where the magnitude of the errors, coupled with the wideness of the melting specifications, makes their toleration possible. To explore the possibilities the whole technique has been studied and various precautions and modifications have been introduced to minimise maximum errors without rendering the process impracticable or uneconomic.

It is emphasised that the highest accuracy is to be expected where large numbers of casts are melted to a single specification, permitting concentration on a relatively narrow range of composition. In the authors' work this has been possible in the case of two high-alloy steels, and many thousands of casts have been successfully analysed. Full details of the technique, the lines used, and the results obtained are given.

In addition, working details and typical results are given for the case of mixed batches of low-alloy steels. Although the rather lower accuracy attainable under such conditions, together with, in general, much narrower melting specifications, has so far prevented the successful large-scale application of this procedure by the authors to the routine works analysis of such low-alloy steels, considerable use has been made of the method in special cases. Moreover,

conditions in individual works vary, and where they are such as to permit the concentration of a more limited range of compositions on individual plates, higher accuracy and more successful applications are to be expected for these materials also. It is hoped that the indications and data given will assist in such development.

The Determination of Low Alumina Contents in Steel by Spectrum Analysis. C. G. Carlsson. (Jernkontorets Annaler, 1942, vol. 126, No. 5, pp. 161–176). (In Swedish). The author describes in detail a method he developed for determining exceedingly low aluminium contents in steel. The sample is dissolved in dilute nitric acid, and a spectrum analysis is made by applying the solution to the carbon electrodes of a direct-current arc. By trying several variations in procedure a method was developed by which the mean error in determinations for any one specimen was about $\pm$ 5%. By taking the mean of three results it was possible to make determinations of low aluminium with an absolute variation of less than $\pm$ 0·001%. This is an accuracy equal to that previously obtained with spark excitation. The arc method also has the advantage that the interference of other alloying elements is practically negligible; for instance, 0·2% of molybdenum affects the aluminium determination with spark excitation, whilst as much as 2·0% has no effect with the arc method.

Routine Colorimetric Determination of Titanium in Chromium Steels. L. Silverman. (Industrial and Engineering Chemistry, Analytical Edition, 1942, vol. 14, Oct., pp. 791–792). The author describes the procedure for making simple routine determinations of titanium in certain steels. The sample is dissolved in a mixture of hydrochloric and nitric acids and fumed in perchloric acid, the chromium trioxide is filtered off cold and the titanium determined colorimetrically.

The Chemical and Physico-Chemical Analysis of Iron and Steel—Twelve Years' Advancement. E. C. Pigott. (Metallurgia, 1942, vol. 26, June, pp. 73–74; July, pp. 113–115; Aug., pp. 145–147; Sept., pp. 189–191; Oct., pp. 202–204; vol. 27, Nov., pp. 31–33; Dec., pp. 80–82). The author gives an exhaustive and descriptive bibliography of methods of analysing ferrous metals which were published during the period 1930–1941 inclusive.

Equipment for Determining Moisture in Coal. O. W. Rees and K. F. Bursack. (Industrial and Engineering Chemistry, Analytical Edition, 1942, vol. 14, Sept., pp. 729–731). The authors report on successful attempts to determine the moisture contents (5–19%) of four qualities of Illinois coal by means of a semi-automatic "moisture tester." This apparatus, which is illustrated, is frequently used in the U.S.A. for the examination of food products and powders. Its main feature is an electrically heated chamber, combined with a balance in such a way that readings can be made without removing the sample from the chamber.

BOOK NOTICES

(Continued from pp. 112 A–113 A)

HIRST, H. *X-Rays in Research and Industry*. 8vo. Pp. 96, illustrated. Melbourne, 1942: Tait Publishing Co. Pty. Ltd. (Price 7*s*. 6*d*. cloth, 5*s*. paper).

The author of this small book is Assistant Director of Metallurgical Research at the University of Melbourne and is temporarily engaged as Manager of the Metallurgical Division, Ordnance Production Directorate, Ministry of Munitions, Australia.

The subject-matter is substantially the same as that of a series of lectures given under the same title before the Melbourne University Metallurgical Society in 1941. The purpose of the lectures was to indicate the types of problems in industry and in research, and in particular those problems coming within the field of physical metallurgy. In the publication of these lectures, the opportunity has been taken to rearrange some of the material, and it is hoped that in its form the book will fill a great need in providing in one small volume a thorough and self-contained study of the principles of X-ray technique and the versatility of its application. The contents are as follows: I. Production of X-Rays; II. Properties of X-Radiation; III. Structure of Crystals; IV. Methods of Crystallographic Examination; V. Application of the X-Ray Methods; VI. Industrial Radiography.

Dr. H. Lipson points out that there are many obvious errors. On page 11, for instance, "e" is printed for "ρ"; on page 13 "tetragonal" and "hexagonal" are interchanged in Table 2; on page 49 "Cu_2MnAl" should replace "CuMnAl"; and on page 50, "$CuAl_2$" should replace "$CuAl_3$." The author has also not been careful about references. For instance, Fankuchen (ref. 6, page 16) is not concerned with the separation of α_1 and α_2; Bradley and Jay (ref. 19, page 30) do not give a detailed description of their camera, and this will be more readily obtained from ref. 30; the description of Hume-Rothery's camera is wrong (page 44).

Several of the explanations also are not correct. The continuous radiation is due to the stopping of the electron beam, and not to the removal of electrons from the atom (page 9); the description of the Θ factor (page 40) is misleading; the method of calibrating cameras (page 33) has been shown to be invalid; and the descriptions of the methods for analysing powder photographs (page 37) are far too optimistic.

In discussing the errors in the measurement of powder photographs (page 31) the word "inversely" has accidentally slipped in. Although these faults are many, the general scheme of the book is good and it is mostly quite well and competently written.

Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf. XXV. Bd. Herausgegeben von Friedrich Körber. La. 8vo. Pp. 209, illustrated. Düsseldorf, 1942; Verlag Stahleisen m.b.H.

In celebration of the jubilee of the Kaiser-Wilhelm-Institut für Eisenforschung after 25 years of research work this 25th volume has been issued; the current 24th volume of technical reports ends in the ordinary way at the end of 1942. The special volume is in three parts. The first part consists of an account, edited by W. Dönges, of

the foundation in 1917 and of the history of the development of the Institute. The second part comprises a review of the investigations and research work carried out by the Institute; in this, the various departments and the different testing laboratories are dealt with separately. The third part contains a list in chronological order of all the technical reports published, together with separate author and subject indices.

BIBLIOGRAPHY

(Continued from pp. 70 A–72 A)

AMERICAN WELDING SOCIETY. "*Welding Handbook.*" Second edition, pp. 1593. New York, 1942: The Society. (Price $6.00.)

ASSOCIATION OF IRON AND STEEL ENGINEERS. "*Specifications for Electric Overhead Traveling Cranes for Steel Mill Service.*" 4to, pp. 29. Illustrated. Pittsburgh, 1942.

BIRINGUCCIO, V. "*The Pirotechnia of Vannoccio Biringuccio.*" Translated from the Italian, with an Introduction and Notes by Cyril Stanley Smith and Martha Teach Gnudi. Publication sponsored by the Seeley W. Mudd Memorial Fund. 8vo, pp. xxvi + 476. Illustrated. New York, 1942: American Institute of Mining and Metallurgical Engineers.

BURTON, E. F., and W. H. KOHL. "*The Electron Microscope.*" 8vo, pp. 238. Illustrated. New York, 1942: Reinhold Publishing Corp. (Price $3.85.)

COOKSON, W., and A. BOLD. "*Elements of Sheet Metal Work.*" Second rev. ed. 8vo, pp. viii + 119. Kingston Hill, 1942: The Technical Press, Ltd. (Price 6*s*. 6*d*.)

GEOLOGICAL SURVEY OF GREAT BRITAIN. "*Geology of the Forest of Dean Coal and Iron-ore Fields.*" By F. M. Trotter. With contribution by W. C. C. Rose. 8vo, pp. vi + 95. Illustrated. London, 1942: H.M. Stationery Office. (Price 6*s*.) (*See* p. 114 A.)

GREGORY, E., and W. W. STEVENSON. "*Chemical Analysis of Metals.*" Second edition. 8vo. London, 1942: Blackie and Sons, Ltd. (Price 20*s*.)

HIMUS, G. W. "*Fuel Testing.*" Second ed. Pp. 282. London: Leonard Hill, Ltd. (Price 21*s*.)

HOLMES, H. N. "*Strategic Materials and National Strength.*" Pp. 106. New York, 1942: Macmillan Co. (Price $1.75.)

JAKOB, M., and G. A. HAWKINS. "*Elements of Heat Transfer and Insulation.*" New York, 1942: John Wiley & Sons, Inc. (Price $2.50.)

MACKENZIE, L. B., and H. S. CARD. "*The Welding Encyclopaedia.*" Tenth, revised edition, by S. Plumley. 8vo, pp. 712. Chicago, 1942: Welding Engineer Publishing Co. (Price $5.)

MARIN, J. "*Mechanical Properties of Materials and Design.*" 8vo, pp. 273. New York and London, 1942: McGraw-Hill Book Co., Inc. (Price 24*s*. 6*d*.)

MERRITT, H. E. "*Gears.*" 8vo, pp. 414. London: Sir Isaac Pitman & Sons, Ltd. (Price 30*s*.)

MÜLLER, O. H. "*The Polarographic Method of Analysis.*" 8vo, pp. vi + 114. Illustrated. Easton Pa., 1942: Journal of Chemical Education. (Price $1.00.)

NORCROSS, C., and J. D. QUINN. "*How to do Aircraft Sheet Metal Work.*" 8vo. pp. 285. New York and London, 1942: McGraw-Hill Book Co., Inc. (Price 15*s*.)

Norton, F. H. "*Refractories.*" Second ed. 8vo, pp. xiv + 798. New York, 1942: McGraw-Hill Book Co., Inc.; London: McGraw-Hill Publishing Co, Ltd. (Price $7.50.)

Simons, E., and E. Gregory. "*Steel Manufacture Simply Explained.*" Second ed. 8vo, pp. 185. London, 1942: Sir Isaac Pitman & Sons, Ltd. (Price 7*s.* 6*d.*)

Vivian, A. C. *Essential Metallurgy for Engineers. The Causes and the Control of Metallic Properties.*" 8vo, pp. xi + 155, with 33 illustrations. London, 1942: Sir Isaac Pitman and Sons, Ltd. (Price 8*s.* 6*d.*)

REFRACTORY MATERIALS

(Continued from pp. 116 A–117 A)

Acid and Basic Bessemer Refractories. J. H. Chesters. (Iron Age, 1942, vol. 150, Nov. 12, pp. 58–64). The author gives a detailed description of English and American practice in the preparation of acid and basic Bessemer converter bottoms. The life of a converter bottom varies from about 10 to 40 blows, according to conditions. With good conditions and a favourable manganese/silicon ratio, the average plug life may be as high as 34 blows. It is frequently observed that tuyères wear back preferentially leaving the rammed mass and fillers standing above the rest of the material. Sometimes one tuyère goes back at a rate out of all proportion to that shown by the remainder. This rate may be as high as 1 in. per min. It has been suggested that boring may be due to the presence of an inferior tuyère, resulting in rapid wear, which becomes a self-accelerating process. A comparison of the properties of the longest and shortest tuyères in a used acid converter plug does not support this theory. It is possible that when two tuyère holes are abnormally close together, a cavity is produced in the tuyère end; once this has formed, a quantity of metal will tend to fall into it, due to the local reduction of pressure, and this metal will be set in rapid motion by the blast in much the same way that a light ball spins on a jet of water; the intense oxidation of this metal and its superheated state will make it highly corrosive.

Standard Refractories for Tapping Steel. (Jernkontorets Annaler, 1942, No. 8, pp. 358–375). (In Swedish). Particulars are given of the Swedish standard specifications for refractories for steelworks' ladles which include lining bricks, launders and stoppers. These have been accepted as standards by Jernkontoret.

FUEL

(Continued from pp. 117 A–120 A)

The Underfeed Stoker for Industrial Furnaces. E. L. Tinley. (British Steelmaker, 1943, vol. 9, Feb., pp. 62–65). After pointing out some advantages in using the underfeed type of stoker, the author describes its application to forging, billet and heat-treatment furnaces. Experience has shown that a very important saving of fuel is obtained as compared with hand-firing for the same furnace capacity.

Operating and Maintaining Gas-Fired Industrial Furnaces. H. Schwiedessen. (Stahl und Eisen, 1942, vol. 62, Aug. 27, pp.

727–734). The author discusses measures for ensuring that gas-fired industrial furnaces are operated and maintained in the most economical and efficient manner. These measures include the training of personnel, drawing up furnace operation instructions, the adjustment of the air/fuel ratio to produce the best results, and automatic furnace regulation.

Gas Burners. G. Neumann. (Iron and Steel Institute 1943, Translation Series, No. 128). This is an English translation of a paper which appeared in Stahl und Eisen, 1936, vol. 56, Aug. 20, pp. 941–952, in which the relative merits of low-pressure-gas fan-blast burners and high-pressure-gas air-suction burners for large annealing furnaces are discussed.

Anthracite Coal Preparation at Onllwyn, Glam. (Iron and Coal Trades Review, 1943, vol. 146, Feb. 5, pp. 193–194). A brief description is given of the washing, drying and dirt-tipping plant for anthracite at the central washery of Evans and Bevan, Ltd., Onllwyn, South Wales. There are two washing units with a capacity of 100 tons and 150 tons per hr. respectively, a slurry-treatment plant and a rotary drier.

The Analysis and Testing of Coal in Relation to its Properties and Utilisation. A. C. Fieldner. (Melchett Lecture: Journal of the Institute of Fuel, 1942, vol. 16, Oct., pp. 5–20). In 1904 the United States Geological Survey established a coal-testing plant, and this was the beginning of organised fuel investigation in the United States on a national scale; in 1910 this was taken over by the Bureau of Mines. In this paper the author reviews the contributions of the Bureau from 1910 to the present time to the development and improvement of testing methods, and their application to the evaluation of those properties of coal which are important in its preparation and use, either directly as a fuel or for the production of gas, coke, liquid fuel, or chemical products.

The Analysis of Coal. (Coke and Smokeless-Fuel Age, 1943, vol. 5, Jan., pp. 7–9). The scope of the laboratory-testing of coal is discussed with particular reference to the behaviour of coals on carbonisation. The most promising apparatus for use in connection with the investigation of swelling is the comparatively large movable-wall vertical oven with bilateral heating developed by the United States Bureau of Mines, for this apparatus simulates coke-oven conditions more closely than is possible with any more simple equipment. It is clear that much research work has yet to be done on the testing of coals before the full-scale bulk test can be superseded, and it is suggested that every coke-oven plant might be built with one or two ovens so arranged that they could be connected to an experimental by-product plant in order that the yield of products could be ascertained by periodical tests.

Recent Progress in Low-Temperature Carbonisation. (Coke and Smokeless-Fuel Age, 1942, vol. 4, Dec., pp. 248–251; 1943, vol. 5, Jan., pp. 10–13). A review is presented of the development

of low-temperature carbonisation processes in Great Britain, the United States and Germany. In Great Britain and the United States there does not appear to be the same clear perception of the fundamental difference between the external and the Spülgas (gas-swept retort) methods of heating low-temperature carbonisation retorts. The important difference is that externally-heated retorts only carbonise coals with good coking properties, whereas the opposite applies to the gas-swept retort which requires a non-coking coal. The point seems to have been reached in Germany at which really large-scale development of low-temperature carbonisation of non-coking coal is about to begin.

Proposals for the Efficient Design, Equipment and Operation of Gas Producers, especially for Open-Hearth Furnaces when Gasifying Rhine-Westphalian Coals. Part I. G. Neumann. (Archiv für das Eisenhüttenwesen, 1942, vol. 16, Dec., pp. 201–214). As the German steelworks are making increased use of producer gas for open-hearth furnaces to replace coke-oven gas, the author puts forward proposals for improvements in the design and operation of gas producers. He makes a plea for the standardisation of design and dimensions of producers and their fittings. The need for a standard grate is stressed. The details of a proposed producer with an inside diameter of 2·6 m. are given with diagrams. Regulation of the coal feed, eccentric and concentric grates and the advantages of a water-cooled casing are discussed in detail. It is shown that, inside a producer, the greatest resistance to the distribution of the blast is offered by the slag zone, and the magnitude of this resistance depends on the free grate area; this factor is therefore of the greatest importance when considering measures to increase efficiency.

PRODUCTION OF IRON

(Continued from pp. 120 A–121 A)

Blast-Furnace Practice in the Smelting of Ore Fines and the Determination of the Furnace Profile and Production. W. Loorz, W. Feldmann and M. Paschke. (Stahl und Eisen, 1943, vol. 63, Jan. 7, pp. 2–11). Since the incorporation of Styria in the German Reich the production of Styrian iron ore has been greatly increased. This is a spathic iron ore containing 30–33% of carbon dioxide. The existing sintering and calcining plant could not cope with the increased production; some of the German works were thus faced with the problem of smelting burdens with a high proportion of fines and the difficulty caused by the evolution of carbon dioxide. In this paper the authors report on a full-scale investigation of the smelting of this ore. A special appliance for the continuous

sampling of the gases from the stack wall to the centre was fitted, and curves of the changes in carbon-dioxide content obtained. When smelting calcined ore with a large proportion of fines, its low mechanical strength, high reducibility and the alkali content caused irregular working and the formation of scaffolds. The economic smelting of Styrian calcined ore requires close control of the burden composition and of the quantity and temperature of the blast. A peculiar feature of the process is that it increases the oxygen content of the blast. The area of the stack cross-section is an important factor when smelting this ore; the larger it is the better. The ratio of this area to the total tuyère area should be 90 to 100.

The Production of Pig Iron in the Low-Shaft Electric Furnace. M. Kauchtschischwili. (Iron and Steel Institute, 1943, Translation Series, No. 125). This is an English translation of a paper which appeared in Stahl und Eisen, 1941, vol. 61, Nov. 13, pp. 1033–1035. (*See* Journ. I. and S.I., 1942, No. I., p. 218 A).

The Grindability of Blast-Furnace Slags. G. Mussgnug. (Zement: Stahl und Eisen, 1942, vol. 63, Jan. 28, pp. 74–75). The author presents and discusses data on the power requirements for grinding light and heavy blast-furnace slags.

Ferro-Alloys in Australia. W. Hewitt. (Institute of Australian Foundrymen: Foundry Trade Journal, 1942, vol. 69, Feb. 11, pp. 119–122). The author reviews the availability in Australia of the minerals necessary for the production of ferro-silicon, ferro-manganese, ferro-chromium, ferro-tungsten and ferro-vanadium. He describes briefly how some of these alloys are made in Australia and their use in cupola practice.

FOUNDRY PRACTICE

(Continued from pp. 121 A–127 A)

Rationalisation in Iron Foundries. F. L. Meyenberg. (Metallurgia, 1943, vol. 27, Jan., pp. 91–93). The author explains the meaning and purpose of rationalisation as applied to industrial undertakings. The instruments of production research are studies of various kinds going on in the works, partly as routine work, partly as special investigations. They can be summarised under the headings: (*a*) Testing and inspection; (*b*) organisation studies; (*c*) work and time studies; and (*d*) costing studies. It is a mistake of many consultants that they specialise only in one branch, such as speed of working, or clearness of statistics. They develop this speciality and its instrument, *e.g.*, time studies, or the costing system, to a high perfection, but neglect other aspects. The result is an inequality of development which may completely eclipse

the profit obtained by the partial improvement, or at least does not allow for the full success of the measures proposed.

Cast Iron and the Foundry Industry. J. E. Hurst. (Metallurgia, 1943, vol. 27, Jan., pp. 85–87). The author reviews some recent developments in the production of castings of high-strength cast iron and indicates some directions in which progress in this field is contributing to the war effort.

Casting Design for Malleable Iron. J. H. Lansing. (American Foundrymen's Association: Foundry, 1942, vol. 70, Nov., pp. 76, 157–159). The author makes recommendations for the improvement of the quality of malleable iron castings. These include: (1) The purchaser should submit tentative designs to the foundry and obtain their suggestions for improvement; (2) keep the thickness of walls as uniform as possible, avoiding abrupt changes in section; (3) when there are bosses or lugs on the interior, there should be heavy sections of metal leading to the feeding source; (4) make provision for attaching gates and feeders to heavy sections; (5) use as large fillets as possible and avoid re-entrant angles; (6) when possible, do not use dry sand cores; (7) indicate the machining allowance on drawings; and (8) an assembly of two or more small castings is preferable to a single large intricate casting.

The Sintering of Aluminous Minerals and Silts of Natural Moulding Sands in the Heating Electron Microscope. M. von Ardenne and K. Endell. (Giesserei, 1943, vol. 30, Jan. 8, pp. 6–12). The authors describe the method by which a magnetic electron microscope was fitted with a specimen carrier which could be heated by an electric current passing through a platinum wire. Instead of using a plate camera, a vacuum-film camera was fitted. With this apparatus the progress of sintering of suspensions of foundry sand at temperatures up to 1600° C. was followed by obtaining a series of pictures at 4000 diameters. Many of these are reproduced. From a study of these it was deduced that: (1) There is no relationship between the amount of fluxing material present and the temperature at which sintering begins, nor does the amount of flux affect the viscosity of the resulting melt. (2) The individual effect of the cations is the determining factor. (3) At the same temperature and concentration (in weight per cent) and with the same weight per cent of $SiO_2 + Al_2O_3$, potash makes viscous melts and ferrous oxide thin melts.

The Sintering of Aluminous Minerals and Silts of Natural Moulding Sands in the Heating Electron Microscope. Inferences for Foundry Practice. E. Wagner. (Giesserei, 1943, vol. 30, Jan. 8, pp. 12–13). The author discusses the applications in the foundry of the conclusions reached regarding the sintering of moulding sands by M. von Ardenne and K. Endell (*see* preceding abstract). The melting point of moulding sand is evidently nothing like so important in determining its behaviour in contact with molten metal as has been thought. The best moulding sand is not that

with the highest refractoriness, but rather the one in which, because of a certain flux content, a fritting of the grains takes place, with the result that, when the casting is cleaned, the sand is knocked off in flakes or scales, leaving a smooth surface on the casting. The sintering temperature of the sand need not be as high as 1600° C. For thin-walled steel castings 1250° C. is sufficiently high; for grey iron and malleable iron it may be still lower, but this has not been investigated yet.

Rammability, Flowability and Density of Foundry Sands. E. O. Lissell and E. J. Ash. (Foundry, 1942, vol. 70, Oct., pp. 78–79, 151–153; Nov., pp. 80–81, 151–154). This is a report on further tests of the properties of Ottawa round silica sand, and Ohio sharp silica sand made up with various binders (*see* Journ. I. and S.I., 1942, No. I., p. 9 A, for a summary of the previous investigation). The results of permeability and flowability tests on sands mixed with different types of binder are presented and discussed. Contrary to the action of water, linseed oil decreases the intergranular friction; the density of the sand therefore increases when oil is added to washed sand until a critical oil-film thickness is reached at about 0·5% by weight of oil. The physical properties of a cereal binder vary considerably within a very small range of water content. Water added to a sand-cereal mixture will increase the strength of the cement surrounding the sand grains very rapidly until about 1% has been added. Water added to a dry mixture of sand and clay causes a pasty binder to form which covers the grains with a layer of clay. The maximum spread of grains will occur at the point where the clay has reached its optimum degree of swelling and strength; the more clay added to the sand, the more water will be necessary to bring out the optimum strength.

Metal Penetration in the Mold. E. E. Woodliff. (American Foundryman, 1942, vol. 4, Nov., pp. 6–7). The author distinguishes between two types of penetration of metal into sand moulds, one characterised by extreme surface roughness over vertical walls, and the other by fins of metal penetrating into cracks in the mould. He points out that the latter type is less likely to occur if the sand is a mixture of a fairly wide range of grain sizes than if the range is very narrow, although the average grain size is the same in both cases.

The Effect of Six Grains of Sand. L. J. T. Brom. (American Foundryman, 1942, vol. 4, Nov., pp. 19–20). The author describes some difficulties which were encountered in blowing some very slender sand cores $4\frac{1}{8}$ in. long, $\frac{1}{8}$ in. in dia. for most of the length, $\frac{1}{2}$ in. in dia. at one end, with a strengthening wire of No. 16 gauge down the centre. A void was frequently found at the neck where the larger diameter tapered down to $\frac{1}{8}$ in. A screen analysis of the sand showed that the proportion of the largest grains passing through a standard 20-mesh screen was 0·4%; this proportion in the $\frac{1}{8}$-in.-dia. section worked out at only six grains. After taking steps to screen out these large grains, this trouble was eliminated.

The Development of the Centrifugal Casting of Metals during the Nineteenth Century. J. E. Hurst. (Iron and Steel, 1942, vol. 16, Dec., pp. 78–81; 1943, Jan., pp. 186–189). The author reviews the development of the centrifugal casting of metals. The earliest record of the application of this process appears to be the granting of a British patent in 1809 to A. G. Eckhardt. Many of the subsequent patent specifications are surveyed and several of the original drawings of casting equipment are reproduced.

PRODUCTION OF STEEL

(Continued from pp. 127 A–130 A)

A Family Business for Over Two Hundred Years. (British Steelmaker, 1943, vol. 9, Feb., pp. 55–58). A brief account is given of the history of the development of J. Beardshaw and Son, Ltd., Sheffield, which was founded in 1719 by John Beardshaw, a cutler. The firm now manufactures sheets, plough plates and finished tools including saws, chisels, milling cutters and files.

German Control of European Industry. (Iron and Coal Trades Review, 1943, vol. 146, Jan. 22, pp. 113–116). In this paper information is given on the measures taken by Germany in exercising economic control of the European countries which they occupy. This account is based on Report No. 5 of the Inter-Allied Information Committee entitled "The Penetration of German Capital into Europe."

The Conservation of Steelmaking Raw Materials. C. M. Parker. (Welding Journal, 1942, vol. 21, Nov., pp. 747–755). The author discusses the steps steelmakers in the United States have taken to economise in the use of aluminium, manganese, vanadium, tungsten and nickel, and presents data on the hardenability of some of the National Emergency steels.

Raw Materials for Steel Manufacture. H. J. French. (A.S.T.M. Bulletin, 1942, Aug., pp. 29–31). This was the author's contribution to a discussion on Alternate Alloy Steels and Conservation of Strategic Alloys. An outline is given of some of the measures taken in the United States to conserve nickel, chromium, tungsten and vanadium.

Conservation of Aluminium and Manganese. C. H. Herty, jun. (A.S.T.M. Bulletin, 1942, Aug., pp. 31–32). In this contribution to a discussion on Alternate Alloy Steels and Conservation of Strategic Alloys the author stated that the consumption of aluminium in the production of steel in the United States has been reduced from 0·698 lb. to 0·562 lb. per ton of steel; this has involved an increase in consumption of ferro-silicon, silico-manganese, "alsifer," and titanium. Manganese consumption remains steady at about

12·5 lb. per ton of ingots, but some makers have achieved considerable reductions by changes in deoxidation practice, *e.g.*, by increasing the amount added to the ladle and decreasing that added to the furnace.

Materials Conservation in the Ordnance Department. J. H. Frye. (A.S.T.M. Bulletin, 1942, Aug., pp. 32–33). In this contribution to a discussion on Alternate Alloy Steels and Conservation of Strategic Alloys, the author explained what has been done by the Ordnance Department of the United States War Department to reduce the amounts of alloying elements used in armaments.

Conservation of Elements Necessary for Tool Steels. N. I. Stotz. (A.S.T.M. Bulletin, 1942, Aug., pp. 34–35). In this contribution to a discussion on Alternate Alloy Steels and Conservation of Strategic Alloys the author explained what has been done in the United States to limit the use of tungsten and vanadium in tool steels.

Conservation of Alloys in Stainless Steels. V. W. Whitmer. (A.S.T.M. Bulletin, 1942, Aug., pp. 35–36). In contributing to a discussion on Alternate Alloy Steels and Conservation of Strategic Alloys the author explained that there was little possibility of reducing the amounts of chromium and nickel required in stainless steel, but greater efforts could be directed to the recovery of these elements from scrap.

Amorphous Graphite in the Open-Hearth. R. J. Zemanek. (Steel, 1942, vol. 111, Nov. 16, pp. 99–101 ; Nov. 23, pp. 86–89). The author discusses the use of Mexican graphite in American open-hearth furnaces to make up the reduced amount of carbon caused by the reduction in the proportion of pig iron charged. For basic practice the optimum grain size is between $\frac{3}{4}$ in. and 30 mesh, whilst for acid practice between $\frac{3}{4}$ in. and 8 mesh is best. The high density of the graphite results in much less space being required than if coke is used. Spraying ingot moulds with a suspension of graphite in water is advocated.

The Removal and the Taking Up of Nitrogen in Steel Baths in the Basic Arc Furnace. W. Altpeter. (Stahl und Eisen, 1942, vol. 62, Nov. 26, pp. 997–1001). The author presents and discusses the results of an investigation of the changes in the nitrogen content of molten steel in basic-lined arc furnaces from melting to tapping. The data were obtained from 102 heats in three different furnaces. The following conclusions were reached : (1) The initial nitrogen content depends on the furnace atmosphere ; the fewer leaks in the furnace, the higher will be the nitrogen content of the steel when the charge is melted. (2) In the decarburising period, the less leaks in the furnace, the more rapidly will the nitrogen in the steel be taken up by the furnace atmosphere. (3) The final nitrogen content does not, as a rule, depend on the furnace atmosphere, but a maximum content of 0·001% can only be attained in newly rammed furnaces working with an atmosphere very low in nitrogen.

(4) The factor exerting by far the greatest effect on the influence of the boiling is the rate of decarburisation; the more rapidly this takes place, the lower will be the degree of nitrogen removal. (5) The size of the ore and the distribution and size of the carbon monoxide bubbles also affect the nitrogen removal; for a given rate of decarburisation, the nitrogen removal will be greater the finer the ore and the greater the number of small bubbles. (6) The greater the nitrogen concentration in the bath, the greater will be the proportion removed. (7) There is no clear relationship between the temperature of the bath and the nitrogen removal. (8) The presence of small amounts (about 2%) of the elements nickel, chromium or molybdenum does not hinder the removal of nitrogen. (9) After decarburising to the point where the carbon content has been lowered by 0·80%, most of the nitrogen will have been removed. (10) Under very favourable conditions the nitrogen content can be brought down to 0·001%, the content is usually 0·003–0·005%. (11) No generally applicable curve can be constructed for the relationship between the removal of carbon and of nitrogen, but the standard curve developed by Bonthron (*see* Journ. I. and S.I., 1938, No. I., p. 121 A) can be used as a guide; the greatest absorption of nitrogen takes place during the recarburising period, the average rate being 0·0013% of nitrogen per hr. (12) The amount of nitrogen absorbed when tapping is not influenced by the procedure for adding alloying elements.

Results of Trials with a Graphite Rod Resistor Furnace. A. Kropf. (Stahl und Eisen, 1943, vol. 63, Feb. 4, pp. 94–97). The graphite rod resistor furnace is a cylindrical tilting furnace heated by radiation from one, two or three horizontal graphite rods passing through it (*see* Journ. I. and S.I., 1942, No. II., p. 11 A). In this paper the author discusses some results obtained in the operation of a 2-cwt. furnace of this type. In the first three campaigns 70, 90 and 196 heats were produced. On relining the second time, a slightly moistened corundum aggregate was rammed in with pneumatic instead of hand rammers. As 70% of the heats were of a high-chromium steel for thin-walled castings, a lining life of 196 heats is considered excellent. For the third campaign of 196 heats the average consumption was 1420 kWh. per ton of steel. In a total of 551 heats with a total charge weight of 49·59 metric tons the electricity consumption amounted to 1880 kWh. per ton of steel. Experience has shown that a very clean steel, equal in quality to crucible steel, can be produced in this furnace.

The Melting Together of Bushy Steel Turnings in a Furnace. F. Köhler. (Iron and Steel Institute, 1943, Translation Series No. 126). This is an English translation of a paper which appeared in Stahl und Eisen, 1942, vol. 62, Oct. 29, pp. 921–922. (*See* p. 129 A).

Investigations of the Ternary System CaO–P_2O_5–SiO_2 and its Importance in the Production of Basic-Bessemer Slags. G. Trömel.

(Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung: Stahl und Eisen, 1943, vol. 63, Jan. 14, pp. 21–30). The author discusses the results of an investigation of equilibria in the lime corner of the $CaO–P_2O_5–SiO_2$ system and by reference to these results explains the mechanism of the solidification of basic-Bessemer slags, pointing out how the structures obtained influence the properties of the slag, especially the rate of solution in citric acid. The importance of the oxides of manganese and iron in commercial slags is related to the immiscibility phenomena in the $CaO–P_2O_5–FeO$ system and the reasons for the difficulties in producing good soluble slags in full-scale plant are discussed.

Thermal Stresses in Ingot Moulds. T. Land. (Iron and Steel Institute, 1943, this Journal, Section I.). Cracking, caused by the thermal stresses set up during the casting of ingots, is a frequent cause of ingot-mould failure. A more exact knowledge of the effect of ingot-mould shape and the properties of the ingot-mould iron on the magnitude of the thermal stresses would be of immediate practical value. With this consideration in mind the thermal stresses under certain conditions have been calculated. The paper has been divided into two parts. In Section 1 of Part I. the stresses in a long circular mould have been calculated on the assumption that the physical properties of the ingot-mould iron are independent of temperature and of stress. It is shown that under these conditions the stresses at the outer surface would be roughly equal to the ultimate strength of the ingot-mould iron. The stresses in a very thin mould exceed those in one of normal thickness by about 20%. In Section 2 the theory is developed to take account of the plastic deformation and varying physical constants of the cast iron, and in these circumstances the stresses are shown to be approximately half the ultimate strength of the mould material. Section 3 deals with moulds of non-circular section and Section 4 with end effects. In Section 5 it is pointed out that the surface stresses can be calculated from measurement of the temperature and expansion of the outer mould surface, and the exact relationships are set out. Arising out of this investigation suggestions are made for future experimental work. Part II. of the paper gives the detailed mathematical analysis discussed under Section 1 of Part I.

A Review of the Work of the Ingot Moulds Sub-Committee. R. H. Myers. (Iron and Steel Institute, 1943, this Journal, Section I.). This review of the work of the Ingot Moulds Sub-Committee includes, in addition to reports already published, some unpublished work as well as work in progress or contemplated. This Sub-Committee is a joint sub-committee of the Open-Hearth Committee of The Iron and Steel Industrial Research Council and the Committee on the Heterogeneity of Steel Ingots. The results of the various researches taken as a whole indicate a number of ways by which the performance of ingot moulds may be improved.

These include reduced casting-to-stripping time, adequate cooling facilities, correct wall thickness, correct composition of mould material, improved founding technique in manufacture, and improved casting-pit practice as a whole. Designers of steel plant have in the past paid insufficient attention to providing adequate accommodation and equipment whereby moulds might receive the treatment consistent with the important position they occupy on the cost sheet. Fundamental research should proceed concurrently with work on the more practical side, if for no other reason than to obtain accurate data for designing moulds which will not crack, as against the empirical methods at present used. Some results of such fundamental work are given in Section II. of this review. It seems that, despite war conditions, every effort should be made to ensure that each works should keep full and accurate records of mould history, not only for control within the works but also for collective research purposes.

The "Degree of Rigidity" of Costs. K. Rummel. (Archiv für das Eisenhüttenwesen, 1942, vol. 16, Dec., pp. 227–232). The author develops curves for iron and steel works costing systems, the purpose of which is to show how certain cost items change with changes in the "activity" factor; this factor is that percentage of the possible production capacity at which the plant is working. He explains how to determine a "cost rigidity factor" for a particular department which shows the degree of sensitivity of the costs to changes in the activity factor. The paper is followed by three appendices, abstracts of which are given below.

Effect of the Degree of Activity of an Iron and Steel Works on the Heat Consumption. W. Heiligenstaedt. (Archiv für das Eisenhüttenwesen, 1942, vol. 16, Dec., pp. 232–233). This paper forms an appendix to that of Rummel (*see* preceding abstract). The author gives examples of the calculation of the "cost rigidity factor" for the total power consumption at blast-furnaces and at open-hearth furnaces, using the activity-factor curves given in a paper by B. von Sothen (*see* Journ. I. and S.I., 1932, No. I., p. 471).

The Determination and a List of Cost Rigidity Factors for Steelworks. A. M. Wolter. (Archiv für das Eisenhüttenwesen, 1942, vol. 16, Dec., pp. 233–235). This paper is a second appendix to that of Rummel (*see* preceding abstracts). The author shows how to determine cost rigidity factors for the different items contributing to the total costs of an open-hearth plant.

Determination of the Degree of Rigidity of the Costs of Operating Rolling-Mill Trains. W. Grenz. (Archiv für das Eisenhüttenwesen, 1942, vol. 16, Dec., pp. 235–236). This paper constitutes the third appendix to that of Rummel (*see* preceding abstracts). The author discusses how changes in the activity factor affect the degree of rigidity of the costs of operating a section mill and a tube mill.

FORGING, STAMPING AND DRAWING

(Continued from pp. 130 A–131 A)

Forging 37-mm. High Explosive Shells. C. C. Barrenbrugge. (Iron Age, 1942, vol. 150, Nov. 12, pp. 54–56). The author describes a machine-forging process for the rapid production of hollow shell forgings 37-mm. in dia., the cavity being over 4 in. long and less than 1 in. in dia. The process was developed by the Portland Forge and Foundry Co., Indiana. The bars of raw material are cut into lengths for making two shells which are upset from opposite ends. These are heated to 2000° F., and the shell forging is made in five passes; the dies and tool-holder are made in one piece and the mandrels are fitted so that they can be changed in a few minutes.

The Working of National Emergency Steels. (Machinist, 1943, vol. 86, Jan. 23, pp. 1095–1106). Lists of the National Emergency steels are presented together with data on their forging, heat treatment, machining and application.

Use of the Slide-Rule for Forge Calculations. R. Benson. (Machinery, 1943, vol. 62, Jan. 21, pp. 63–66). The author explains the use of the slide-rule for calculating the weights of bars of round, rectangular, octagonal and oval section, as well as of round and square tapering lengths and the weights of tubes.

The Production of Sintered Carbides and their Application in Wire-Drawing Plants. J. Hinnüber. (Stahl und Eisen, 1942, vol. 62, Dec. 24–31, pp. 1083–1090). The author discusses the effects of the composition and the process of manufacture on the properties of sintered carbide dies. To prevent the cracking of dies when they are subjected to severe stresses it is necessary that the die holders be of very strong steel. For larger wire-drawing and deep-drawing dies the proportion of cobalt should be increased. For wet-drawing, dies sintered under pressure are superior to those sintered without the application of pressure; for dry-drawing the opposite applies. Under certain conditions the addition of a second carbide to alloys of tungsten-carbide and cobalt increases the life of dies.

ROLLING-MILL PRACTICE

(Continued from p. 131 A)

Electrical Drives for a 110″ Reversing Plate Mill. C. J. Porter, C. A. Price and A. F. Kenyon. (Iron and Steel Engineer, 1942, vol. 19, Nov., pp. 73–82). The authors describe a 110-in. plate mill which was installed in 1941 at the Hamilton Works of the Steel Company of Canada, Ltd., with particular reference to the electrical

equipment. The main mill stand is a four-high one with working rolls 38 in. in dia. and 110 in. long and backing rolls 52 in. in dia. The 5000-h.p. wound-rotor induction motor driving the reversing mill flywheel motor-generator set is wound for 13,200 V., and takes current directly from the 13,200-V. bus bar.

Is Maintenance and Design a Partnership? W. J. Fleming. (Iron and Steel Engineer, 1942, vol. 19, Nov., pp. 58–62). The author discusses methods of controlling the electrical equipment of steelworks, giving examples which illustrate how the designer and the maintenance man have co-operated to produce many improvements.

Low Voltage Distribution Systems in Steel Mills. L. L. Fountain. (Iron and Steel Engineer, 1942, vol. 19, Nov., pp. 50–55). The author discusses wiring diagrams for the distribution of low-voltage current in rolling mills giving some examples of actual installations.

Trends in the Design of D.C. Control. H. L. Wilcox. (Iron and Steel Engineer, 1942, vol. 19, Nov., pp. 38–42). The author describes and discusses some improvements in the design of control equipment for direct-current motors in rolling-mill equipment.

Modern Construction of A-C Motor Control. F. A. Wright. (Iron and Steel Engineer, 1942, vol. 19, Nov., pp. 44–48). The author describes a new type of control panel for alternating-current motors which has been recently designed and produced in the United States. They are made up of three basic elements, viz.: the individual controllers, the supporting enclosures for the panels which are called door frames, and the self-standing cubicles for the door frames which are called sections.

Roll Grinding. T. Smith. (Machine Shop Magazine, 1943, vol. 4, Feb., pp. 45–50). The author discusses the design of roll-grinding machines, the selection and care of grinding wheels, cooling agents, and wheel and traversing speeds.

Bearing Metals in Steel Mill Practice. H. A. White. (Metal Industry, 1943, vol. 62, Jan. 29, pp. 71–74). The author presents and discusses data on the properties of bearing metals to the S.A.E. and A.S.T.M. specifications which include bronzes and babbitt metal. Reference is made to the improved life of plate-mill bearings made of a high-grade nickel-bronze having several babbitt-filled pockets in the bearing surface.

Substitute Materials in Steelworks Machinery. E. Rohde. (Stahl und Eisen, 1943, vol. 63, Feb. 4, pp. 85–94). The author gives examples of methods employed at German steelworks to reduce the consumption of metals which are difficult to obtain. These examples include: (*a*) Increasing the bearing surface area of bronze bearings for rolls for the hot-rolling of sheets and, each time rolls are changed, checking the contour to see that wear has not reduced the bevel for leading in the oil to such an extent that the edge of the bearing acts as a scraper and removes the oil from the revolving neck. A considerable saving in bronze per ton of

sheets rolled has been achieved in this manner. (*b*) The surface-hardening of journals for the wheels of travelling cranes. (*c*) The use of blast-furnace tuyeres made of aluminium and Silumin, or of copper with steel backs in place of all-copper tuyeres. (*d*) Substituting composite steel-copper for solid copper in certain types of switch gear. (*e*) The use of steel live rails and cast-iron collector shoes for electric overhead cranes.

The Influence of Water on the Lubricating Value of Mill Bearing Oil. R. P. Dunmire. (Iron and Steel Engineer, 1942, vol. 19, Nov., pp. 30–36). The author describes an investigation of the effect of different quantities of water in lubricating oil for rolling-mill bearings. Details are given of a "lubarometer" which is a machine for determining the tangential drag of lubricating oils at different temperatures, speeds and loads. Curves were obtained with this machine showing the watts consumed per square inch of bearing area at various pressures while holding the temperature and speed constant and changing the constitution of the oil. These indicated quite clearly that the presence of water has a marked effect in lowering the temperature at which an oil film will rupture. A careful study was also made of the power input of a four-high hot strip mill stand, using oil with a moisture content of 0·7% and with a re-refined and dehydrated oil with physical characteristics equal to those of new oil; this study indicated that there was a saving of 7·68% in the power supplied to the stand. Such a saving over one year would be many times the cost of an oil-dehydrating plant and its maintenance. A suitable dehydrating plant is described.

Sendzimir Mill Rolls Strip to Close Tolerance. T. Sendzimir. (Steel, 1942, vol. 111, Nov. 30, pp. 64–68, 74). The author gives details of the design and performance of the Sendzimir mill stand for cold-rolling strip. The work rolls are small in diameter and there are two clusters of backing rolls so that heavy reductions can be made in one pass. (*See* p. 14 A).

HEAT TREATMENT

(Continued from pp. 132 A–133 A)

Valve Spring Manufacture. (Machinery, 1943, vol. 62, Jan. 28, pp. 85–89). A description is given of the methods employed at the works of the Ford Motor Co., in the manufacture of valve springs for aero engines, with some details of the heat treatment and magnetic testing for cracks.

The Technical Development of Lead Patenting and of Batch and Continuous Patenting Furnaces. J. Rath. (Stahl und Eisen, 1942, vol. 62, Nov. 19, pp. 977–981). The author traces the history

of the development of furnaces for patenting wire from about 1850, when charcoal-fired furnaces were used, to the present time when gas-fired continuous furnaces are in operation with lead baths built at the exit end into which the wire passes direct without exposure to the outside air. Diagrams and illustrations of plant in various stages of development are included.

"6–6" Moly Steels Replaced by "4–6." (Machine Shop Magazine, 1943, vol. 4, Jan., pp. 37–39). By a direction of the Ministry of Supply, Iron and Steel Control, the manufacture of "6–6" molybdenum high-speed steel is to cease and this steel is to be replaced by one containing molybdenum 3·9–4·4%, tungsten 5·0–6·0%, chromium 4·0–5·0% and vanadium 1·40–1·60%. In this article recommendations are made on the forging, heat treatment and grinding of the "4–6" steel.

Factors Affecting the Carbon of Casehardened Products. D. McPherson. (Machine Shop Magazine, 1943, vol. 4, Jan., pp. 74–81). The author reviews factors governing the selection of suitable carburising media and the method of treatment for case-hardening and explains how the amount of carbon affects the properties of the case. As the carbon content of the case increases, the tendency towards austenite retention becomes more marked; this is particularly true of the higher alloy types of case-hardening steels when they are quenched directly from carburising. There is no general agreement on the question of austenite retention in finished case-hardened products. It appears fairly certain that a small amount of retained austenite, the percentage being governed by a case hardness of not less than Rockwell C 58 to C 60 after quenching, rather than being detrimental, may be beneficial in that the structure is more stable and therefore more resistant to changes of surface temperature brought about by frictional heat. A martensitic structure is to be preferred under operative conditions which demand high load-carrying capacity with high abrasive resistance, and, the finer the martensitic structure the more suitable it appears to be from the point of view of resistance to wear and pitting. It is suggested that the most important single feature of any part, regardless of its carbon content, if it is designed to resist wear, is that it must possess microstructural uniformity of hardness in conjunction with a surface finish free from machine or grinding cuts. Average surface hardness figures should not be regarded as a criterion of wear resistance. In recent years there has been a tendency to employ direct oil-hardening steels giving a considerably lower hardness but superior microstructural uniformity.

Carburizing Compounds Reconditioned Automatically. S. H. Brams. (Iron Age, 1942, vol. 15, Nov. 26, pp. 67–69). The author gives a brief description of the Newcomb-Detroit plant for reconditioning used carburising compounds. The plant consists of an arrangement of conveyors, a cooler and ash remover, and a

mixer for mixing with a proportion of new compound. The dust conditions are controlled throughout the process so that the atmosphere at the plant is kept clean to the benefit of both men and machinery.

New Uses of Induction Heating. R. Legrand. (Machinist, 1943, vol. 86, Jan. 16, pp. 1079–1081; Jan. 30, pp. 1158–1161). The author explains the principles applied in electric induction heating, discusses inductor block design and presents data on the effect of current frequency on the depth of the heated zone for copper, cast iron, graphite, rail steel and stainless steel. In the second part of the article some applications of induction heating in munition work are described.

The Application of a Soaking Furnace Utilising the Heat of Rolling when Hardening and Heat-Treating Steel. A. Schneider. (Stahl und Eisen, 1942, vol. 62, Nov. 26, pp. 1002–1005). The author describes a furnace installed at the rolling mills of Königs- und Bismarckhütte A.-G. with the object of improving the heat treatment of the high-quality steel bars rolled at this mill which consists of one light and one medium mill train. The furnace is placed just behind the hot shears of the light train in such a way that it can take the product of either train. The quenching tank is immediately behind it. The inside dimensions of the furnace are $5 \times 1 \times 0{\cdot}6$ m. It is fired with producer gas supplied to four burners on each side. The steel is always in a reducing atmosphere and very little scale is formed. The furnace is kept at a temperature in the 780–830° C. range, the actual figure depending on the steel to be treated. The temperature of the quenching bath can be controlled by a steam line and the liquid is agitated by compressed air. The installation of this furnace has proved very satisfactory in that complete recrystallisation of the bars takes place, rolling stresses are relieved and a uniform temperature at the surface, core and ends of the bars is attained. Tables are presented showing the gas consumption, furnace temperature, throughput, bar dimensions and mechanical properties of high carbon steel and of chromium-vanadium steel bars treated in this furnace. There has been a marked improvement in the uniformity of the properties of the bars.

WELDING AND CUTTING

(Continued from pp. 133 A–135 A)

Welding from an Engineering, Metallurgical and Economic Standpoint. D. Clark. (Australian Institute of Metals: Australasian Engineer, 1942, vol. 42, Nov. 7, pp. 163–170). The author discusses the following aspects of welding mainly from a metal-

lurgical standpoint: (1) Thermit fusion welding; (2) electric resistance welding; (3) gas welding; (4) arc welding; (5) the metallurgy of welding; (6) failures of welded structures; (7) relief of weld stress; (8) the economics of welding; and (9) the future of welding.

Investigation of Welding Problems through Metallurgy. L. L. Wyman. (Iron Age, 1942, vol. 150, Oct. 29, pp. 37–39). The author cites some examples of the discovery of the fundamental cause of faulty welds by the study of micrographs of sections through the welds.

Heliarc Welding of Stainless Steel. T. E. Piper. (Welding Journal, 1942, vol. 21, Oct., pp. 490-S, 523-S). The author gives a brief description of a method of welding stainless steel developed by Northrop Aircraft Incorporated. In this method a special torch is used containing a carbon electrode around which flows helium gas in a steady stream during welding. The specific heat of helium is over five times that of air, and, when in motion, the gas prevents the accumulation of heat round the weld, thereby keeping it cooler and giving better penetration with less distortion. With this process (called "Heliarc welding") stainless steel less than 0·010 in. thick can easily be welded.

High Speed Tube Welding. G. V. Slottman. (Iron Age, 1942, vol. 150, Nov. 26, pp. 59–66). The author describes and illustrates a tube mill at the works of the Borg-Warner Corporation. In this mill, flat steel strip is formed into tube by passing it through ten pairs of rolls; the tube then travels, supported by six pairs of water-cooled rolls, under an oxy-acetylene welding head. This head has 81 flame orifices arranged so that two rows of flames preheat the surface along two lines parallel with the seam; this is followed by a single row impinging directly on the joint. The welding head is designed so that the proportion of oxygen in the flame at each of the preheating orifices gradually decreases to give an almost neutral flame at the point where welding commences. Tubing can be produced in this mill at rates up to 200 ft. per min.

Weld Quench Gradient Tests. W. H. Bruckner. (Welding Journal, 1942, vol. 21, Oct., pp. 496-S–500-S). The author describes a form of weldability test in which the effects of a wide variety of cooling rates are reproduced in a single specimen. In this test a specimen of plate is prepared in the shape of a right-angled triangle with the corners forming the acute angles cut off. A convenient size is one with the two shortest sides 6 in. and 3 in. long. The specimen is then clamped to a leg in a water tank with the 3-in. side and part of the hypotenuse submerged so that the 6-in. side projects above the surface at an angle of 30°; a bead of weld metal is deposited along this edge commencing at the water level. Water at constant temperature is circulated through the tank. After welding, a strip along the heat-affected zone is polished and a hardness survey made at intervals of $\frac{1}{8}$ in. In this way hardness values

are obtained representing a wide range of cooling rates from drastic water-quenching to slow cooling in air. The results are given for a specimen of 3·5%-nickel steel ½ in. thick. This test is referred to as the "weld quench gradient test." At present there are no data available on the actual heating and cooling rates under these conditions, but when this requirement has been met the usefulness of the test will be greatly increased.

Worn High Speed Steel Tools Tipped with Carbide. J. S. Gillespie. (Iron Age, 1942, vol. 150, Nov. 26, pp. 70–71). The author describes how tungsten-carbide tips can be brazed to worn high-speed steel tools. In many cases it is not necessary to grind a recess for the tip as it can be brazed to a flat surface. For the brazing operation the tool should be heated quickly and no more than necessary, and plenty of flux should be used to keep the chromium from oxidising.

Reclaiming High-Speed Steel Tools. T. Sutton. (Steel, 1942, vol. 111, Nov. 30, pp. 88–90). The author describes a process of reconditioning worn or chipped high-speed steel tools. The process is known as "Suttonizing" and it consists of depositing a layer of metal on the worn part with a proprietary welding rod and then grinding to shape. Preheating is required, but no subsequent heat treatment; the finished surface has the cutting qualities of high-speed steel.

The Spot Welding of 0·040 in. S.A.E. X-4130 Steel. W. F. Hess and D. C. Herrschaft. (Welding Journal, 1942, vol. 21, Oct., pp. 441-S–447-S). The authors describe an investigation for the purpose of discovering a suitable spot-welding technique to produce satisfactory welds in thin sheet (0·040 in.) of steel S.A.E. X-4130 which contains carbon 0·30%, chromium about 1% and molybdenum about 0·20%. The rapid cooling of this thin sheet when the current is shut off causes a hard and brittle weld. It was found that by applying a current after the weld, so as to give it a tempering treatment, a very marked improvement in the mechanical properties was obtained. The time interval between the welding and tempering currents has a critical minimum but no critical maximum value. A tempering current of only 6 cycles' duration is sufficient to obtain the maximum beneficial effect. Curves showing the changes in hardness and shear strength of spot welds under different conditions are presented.

Weldability of Carbon-Manganese Steels. (Welding Journal, 1942, vol. 21, Oct., pp. 448-S–450-S). This paper constitutes the Report by Subcommittee II., Industrial Research Division of the Welding Research Committee of the Engineering Foundation, on an investigation of the weldability of steels containing carbon 0·20% min. and manganese 0·5% min. It was found that the sum of the carbon and one-sixth of the manganese contents was a useful index to the weldability of steels containing carbon 0·20–0·30% and manganese 0·50–1·0%. In general it is considered that steels with more than 0·25% of carbon and 1% of manganese are not

weldable without excessive hardness unless some form of pre- or post-treatment is applied. The factor "carbon plus one-sixth manganese" can also be applied to cast manganese steels.

Weldability of Carbon-Manganese Steels: Weld-Bead Hardness and Weld-Bead Bend Tests. O. E. Harder and C. B. Voldrich. (Welding Journal, 1942, vol. 21, Oct., pp. 450-S–466-S). This paper constitutes a Report of work carried out by the Battelle Memorial Institute, at the request of Subcommittee II. of the Welding Research Committee (*see* preceding abstract), on the weldability of carbon-manganese steels. Hardness and bend tests were carried out on ten commercial steels, three experimental steels and three cast steels containing 0·20–0·35% of carbon and up to 1·70% of manganese; plate thicknesses of $\frac{1}{4}$, $\frac{1}{2}$, 1 and 2 in. were used. Full details of the testing procedure are given together with tables of the results obtained. The general conclusions from the data are presented in the preceding abstract.

Weldability Tests of Carbon-Manganese Steels. C. E. Jackson, M. A. Pugacz and G. G. Luther. (Welding Journal, 1942, vol. 21, Oct., pp. 477-S–484-S). The authors report on an investigation of the effect of the carbon and manganese contents on the mechanical properties and weldability of steel. Twenty-nine commercial steels were tested, the carbon and manganese contents of which varied from 0·05% to 0·50% and from 0·40% to 1·67%, respectively. For determining weldability, emphasis was placed on the V-notched slow-bend test; for comparison some T-bend tests were made (these tests are referred to in an earlier paper by Jackson and Luther, *see* Journ. I. and S.I., 1941, No. I., p. 171 A). The conclusions reached were: (1) There is a definite correlation between the results of the above two tests; (2) normalised steel should be used for studying the effect of composition on weldability; (3) in determining the effect of welding on a steel for a particular structure, the tests should be carried out with the steel in the condition in which it is to be fabricated; (4) the maximum hardness obtained in the heat-affected zone is the same whether the steel is welded in the normalised or the as-rolled condition; and (5) the determination of the Ar_3 transformation temperature at cooling rates equivalent to those obtained in the welding cycle seems desirable.

Report of Tee-Bend Tests on Carbon-Manganese Steels. L. C. Bibber and J. Heuschkel. (Welding Journal, 1942, vol. 21, Oct., pp. 485-S–490-S). The authors report on an investigation of the weldability of carbon-manganese steels undertaken by the Carnegie-Illinois Steel Corporation. A brief description of the T-bend test is given with diagrams showing how the specimens were prepared. The steels tested were divided into four groups containing carbon and manganese 0·21–0·23% and 0·39–0·44%, 0·27–0·29% and 0·54–0·75%, 0·35% and 0·90%, and 0·32% and 1·49%, respectively. Any one of the three values—namely, total angle at maximum load, total angle at commencement of failure and type of fracture—

can be used as a criterion of weldability in this test; the second value is perhaps the most indicative. Despite the poor results obtained from low-carbon killed steel, the differences in steel-making practice, *i.e.*, rimming, semi-killing and killing, seem to have little effect on the weldability, particularly if other hardening elements are reduced to compensate for the presence of silicon. When the testing is done at 80° F. the temperature of the specimen when commencing the weld has little effect on the total angle of bend at first fracture; when the testing is done at − 20° F., however, the temperature when welding is started has a marked effect on this angle, for its value is much greater if the specimen is preheated.

Changes in the Interpretation of the Weldability of St 52. E. Helin. (Teknisk Tidskrift, 1941, vol. 71, Dec. 27, pp. 185–191). (In Swedish). The author reviews investigations of the weldability of steel St 52, in particular the design and properties of welded plate girders of this steel. Severe restrictions were at first placed on the welding of steel St 52, but with improvements in the control of grain size, in welding rod composition and technique, and in the positioning of the welds, the steel is now accepted for the construction of many types of welded structures.

CLEANING AND PICKLING OF METALS

(Continued from pp. 90 A–91 A)

Submerged Combustion Takes its Place in the War Industries. W. G. See. (Wire and Wire Products, 1942, vol. 17, Oct., pp. 544–550, 619). The author discusses three years' experience in the use of the "submerged combustion" method of heating and agitating pickling tanks. In this method gas-burners are submerged in the pickling solution; to light them they are purged with compressed air and a hot-wire igniter first lights a pilot flame, which in turn ignites the main gas flow. The products of combustion are exhausted directly into the solution, which causes strong agitation. Five cases are cited with data on the life of burners and cost of replacements.

Flame-Priming Method of Preparing Steel Surfaces for Painting. E. W. Deck. (Iron Age, 1942, vol. 150, Oct. 22, pp. 80–82; Oct. 29, pp. 44–48). The author describes the flame-priming or flame-descaling process for preparing steel for painting. The burner heads used may be from 1 in. to 12 in. in width; a 6-in. head is a common size, and this contains 49 flame-holes 0·02 in. in dia., $\frac{1}{8}$ in. apart. The effect of the heat on rust is first to dry out the physically adsorbed moisture and break down the rust, leaving an anhydrous oxide; simultaneously the reducing gases in the flames reduce the

oxide to ferroso-ferric oxide or black magnetite. The formation of this black powder indicates that all moisture has been driven off. The results of corrosion tests on steel panels which had been flame-descaled before coating with different paints are given and demonstrate the superior properties of steel when given this treatment.

COATING OF METALS

(Continued from pp. 91 A–94 A)

Hard Chromium Plating. A. Fletcher. (Metal Finishing, 1942, vol. 40, July, pp. 355–358). The author describes many applications of the hard chromium plating process, including such as dies, the contact surfaces of gauges, the building up of worn parts and parts which have been machined undersize, rams for pressing plastics and moulds for the glass industry.

Steel Chromizing. C. M. Cosman. (Iron Age, 1942, vol. 150, Nov. 26, pp. 49–53). The author reviews the literature on the development of the process of "chromising" steel, in which a stream of chromium-chloride gas is passed over the steel in a retort or muffle, thus causing chromium to be diffused into the steel surface. The process has been described in a paper by G. Becker, K. Daeves and F. Steinberg (*see* Journ. I. and S.I., 1941, No. II., p. 88 A). The consumption of chromium amounts to 0·45–0·48 oz. per sq. ft. for the normal case thickness of 0·0004 in., and there is practically no chromium loss.

The Formation and Evaluation of Zinc Coatings. I. General and Theoretical. II. The Hot-Dipping Process. III. Modifications of the Hot-Dipping Process. IV. Electro-Galvanising. V. Sherardising and Spraying. VI. Corrosion. VII. Corrosion. VIII. Methods of Testing. (Sheet Metal Industries, 1942, vol. 16, July, pp. 953–958, 968; Aug., pp. 1127–1131, 1143; Sept., pp. 1301–1307; Oct., pp. 1481–1487; Nov., pp. 1666–1671, 1674; Dec., pp. 1850–1856; 1943, vol. 17, Jan., pp. 69–74; Feb., pp. 243–248, 252). In Part I. of this series of articles some statistics on zinc production and on the quantities of steel which are zinc-coated annually by hot-dipping, electro-deposition, Sherardising and spraying are presented. The zinc-rich end of the iron-zinc equilibrium diagram is discussed and applied to a study of the formation of hot-dip coatings. The cementation, electro-deposition and spraying processes are briefly described. In Part II. particulars of recent developments in the hot-dip galvanising process are given. Reference is made to the function of glycerine in the flux layer on top of the molten zinc, which is to increase the surface of contact between the material to be dipped and the flux, thus making the removal of any moisture more certain. The modifications of the galvanising process which are briefly described in

Part III. include: (1) "Dry" galvanising in which about 0·15% of aluminium is added to the bath to ensure that the zinc-iron alloy layer is as thin as possible; (2) "galvannealing" in which the coated articles are given a heat treatment at about 650° C.; (3) the "flame-seal" process in which the coating is subjected to the action of a controlled flame; (4) the lead-zinc process the object of which is to prevent the bath being contaminated with iron compounds; and (5) continuous galvanising. The effect of additions of aluminium, tin, lead, cadmium and antimony to the zinc bath are also dealt with in this part. Electro-galvanising is dealt with in Part IV. Acid, alkaline, chloride and bright zinc plating solutions, and the operating conditions for each are discussed in turn. For the anodes, pure zinc, either rolled or cast, is the most suitable material; no sludge is formed if such anodes are used, whereas anodes containing copper, iron, arsenic, tin or lead give rise to sline in the acid bath, and are equally undesirable in the alkaline bath where they go into solution. The compositions of some solutions for zinc-cadmium alloy plating are given. In Part V. the Sherardising and metal-spraying processes of forming zinc coatings are described. In Sherardising, the parts to be coated are cleaned and put in a cylindrical container together with a quantity of very fine zinc dust (about 1 cwt. of dust for 5 cwt. of parts); the cylinder is heated to about 375° C. and rotated for 2–4 hr., so as to tumble the parts in the dust. The coating is dull grey when first produced, but on exposure it becomes darker; it may contain 8–10% of iron, but the lower the iron content the better will be the corrosion resistance. There are three processes of spraying zinc in which the metal is in wire, molten or powder form respectively. The density of a sprayed coating is about 10% less than that of the metal in the rolled or wrought state. In Parts VI. and VII. some of the literature on general corrosion and on the corrosion of zinc coatings is reviewed. The present trend of opinion is that coatings made by different processes have very similar properties from the point of view of corrosion, particularly when a comparison is made by long-time exposure tests. In the next part (Part VIII.) a number of accelerated corrosion tests and methods for determining the thickness of zinc coatings are described; among the former are the A.S.T.M. procedure for salt-spray tests and Wernlund's test by immersion at 95° C. in a solution containing 140 c.c. of hydrogen peroxide and 20 g. of acetic acid per litre; among the latter are Britton's test, Cushman's method and the chord method.

Hot-Dip Galvanising Technique. G. Robinson. (Wire Industry, 1942, vol. 9, June, pp. 237–243; Aug., pp. 321–325; Sept., pp. 373–375; Oct., pp. 413–417; Nov., pp. 459–461; Dec., pp. 503–505). In the first part of this series of articles the author explains the theory underlying the hot-dip galvanising of wire and enumerates various developments, in particular some of American origin. Plant for the continuous and batch annealing of wire is described

in the next part. In the third part a bath for degreasing wire drawn with hard soap is described. In the fourth part on pickling it is stressed that acid-pickling is a chemical cleaning process, and that it cannot serve the dual purpose of cleaning and fluxing; methods of controlling the acid strength are discussed. Fluxing is dealt with in the next part, and the composition and properties of some zinc ammonium chloride solutions are given. In the sixth part the crystal structures of iron and zinc and the mechanism of the alloying action of the two metals are discussed at length, and this is applied in the design of the mechanical devices by which the wire enters and leaves the zinc bath.

Temperature Control of Galvanising Kettles. H. Halstead. (Iron and Steel Engineer, 1942, vol. 19, Nov., pp. 64–69). The author discusses the factors on which the maintenance of a uniform temperature of the zinc in a galvanising kettle depends, and the desirable features of the fuel-control equipment. It is recommended that the volume of the kettle should be 50 cu. ft. for each ton (2000 lb.) of steel galvanised per hr., and that there should be 1 sq. ft. of exposed kettle heating surface for each 12,000 B.Th.U. per hr. of heat input; only the upper two-thirds of the kettle walls should be considered as available heating surface.

Zinc Plating. W. Eckardt. (Sheet Metal Industries, 1943, vol. 17, Jan., pp. 109–110, 114). An abridged English translation of a paper on electro-galvanising which appeared in Korrosion und Metallschutz, 1941, vol. 17, Dec., pp. 401–403, in which the results of tests on bright zinc coatings produced with different baths are given (*see* p. 26 A).

The Influence of Various Factors on the Tin Coating on Tinplate. J. Teindl. (Iron and Steel Institute, 1943, Translation Series, No. 130). This is an English translation of a paper which was published in Korrosion und Metallschutz, 1941, vol. 17, Nov., pp. 390–396. (*See* p. 27 A).

Alloy Steel Cladding and Pressure Vessels. H. S. Blumberg. (Iron and Steel Engineer, 1942, vol. 19, Oct., pp. 70–74). The author discusses the production and properties of composite metals made by cladding carbon and carbon-molybdenum steels with corrosion-resistant metals and alloys. The metals and alloys used for the coating fall into three groups, viz., low-carbon steels with 11–27% of chromium, high-chromium nickel steels with or without columbium or molybdenum, and non-ferrous metals. The finished product may be integral or partially bonded. The integral type can be made by integral casting, a heat-pressure method, fusion inter-melting or continuous resistance welding. A partially bonded joint can be obtained by plug welding, spaced resistance welding or strip welding. Partially bonded material can only be used when the clad plate does not require hot mechanical working.

Electrodeposition of Iron-Tungsten Alloys from an Acid Plating Bath. M. L. Holt and R. E. Black. (Electrochemical Society,

1942, Preprint No. 82–27). The authors report on a study of the electrodeposition of iron-tungsten alloys from a plating bath prepared by the addition of small amounts of sodium tungstate to the ferrous-ammonium-sulphate bath. The tungsten content of the alloy was found to increase somewhat with : (*a*) Increase in tungsten content of the bath ; (*b*) decrease in the cathode current density ; (*c*) increase in bath temperature ; and (*d*) decrease in *p*H value of the bath. An increase in the tungsten concentration in the bath was found to decrease the current efficiency of the deposition.

Corrosion Prevention. C. E. Lambert. (Australian Institute of Metals : Australasian Engineer, 1942, vol. 42, Sept. 7, pp. 9–10). The author describes the procedure for cadmium-plating steel aircraft parts which, in the completed assembly, will be in contact with other metals ; as well as the chromate treatment of magnesium.

How to Silver Plate Steel over a Phosphate Coating. P. J. Lo Presti. (Metal Finishing, 1942, vol. 40, Oct., pp. 533–536 : Sheet Metal Industries, 1943, vol. 17, Feb., pp. 259–261, 263). The author reports the results of adhesion tests and salt-spray corrosion tests of silver-plated steel, the silver being deposited over a phosphate coating instead of the more usual nickel or copper coating. It was found that a thin deposit from a 25% phosphoric-acid solution, formed in about 30 sec. at room temperature, improved the adhesion of silver plate. Annealing in an ordinary atmosphere at 750° F. did not decrease the adhesion, but annealing in nitrogen considerably reduced the adhesion. The phosphate coating did not improve the corrosion resistance of the silver coating, and annealing decreased the corrosion resistance.

A Comparative Study of Oils for Supplemental Protection of Black Oxide Coatings on Steel. E. A. Parker and A. K. Graham. (Metal Finishing, 1942, vol. 40, July, pp. 363–364, 367). The authors present the results of an investigation of the resistance to rusting in salt-spray tests of steel panels coated with black oxide with an additional coat of one of several oils. The oils used were of the following types : Mineral oil with and without inhibitors, sperm oil, solvent "antirust" oil and water-soluble oil. The water-soluble oils offered the greatest resistance and the mineral oil the least. Soluble oils are being successfully and economically employed for protecting various oxide-coated parts during assembly, inspection and storage ; they have proved to be very satisfactory for the permanent protection of oxide-coated parts of enclosed assemblies of instruments and dial gauges.

Recovery of Gilding Metal from Clad Steel. A. J. Thompson. (Iron Age, 1942, vol. 150, Nov. 12, pp. 51–53). The United States Ordnance Department has decided to make cartridge cases of brass-coated steel instead of solid brass. As a considerable amount of scrap arises in the course of manufacture and, as the coating contains 90% of copper, the problem arises of recovering this copper from the scrap. In this paper the author describes briefly the

methods by which some American concerns recover this copper. The most successful process is based on the solvent action of cupric ammonium carbonate on copper and zinc. It is a cheap and efficient process well known in the treatment of copper ores. It permits the almost complete recovery of copper and iron separately, the copper in the form of oxide and the iron as unattacked scrap. The amount of zinc recovered is low.

The Testing of Continuity of Thin Tin Coatings on Steel. R. Kerr. (Journal of the Society of Chemical Industry, 1942, vol. 61, Dec., pp. 181–183). The author describes modifications of the hot-water porosity test and the ferricyanide paper test for hot-dipped tinplate, which are suitable for thin electrolytic tin coatings of 2–8 oz. per basis box, as well as a new porosity test based on the amount of iron dissolved under standard conditions by an acid solution, the dissolved iron being determined colorimetrically by means of thiocyanate.

What Causes Fishscaling? W. W. Higgins. (Porcelain Enamel Institute: Sheet Metal Industries, 1942, vol. 16, Nov., pp. 1724–1726; Dec., pp. 1894–1896; 1943, vol. 17, Jan., pp. 111–114). The author reviews the literature on investigations of the causes of fishscaling in enamel coatings on iron and steel, and discusses the results of his own recent investigations. His general conclusions are: (1) Fishscales form more readily over the "solid rim" portion of steel sheet rolled from rimming steel sheet bars; this solid rim forms when the ingot is cut into sheet bars because the core remains sandwiched between two layers of rim steel, although it does not extend entirely to the edge of the sheet on all four sides. (2) Enamel fishscales more readily when both sides of the pieces are enamelled. (3) Fishscaling is more likely to occur when the piece is fired in air than when fired using the oxidation-control method of firing; excessive iron-oxide concentrations at the metal-enamel interface destroys the bubble structure of the enamel and promotes fishscaling. (4) Enamel fishscales more readily when the water-vapour content is high than when it is low. (5) Clear-burning clays in the enamel make fishscaling worse, and clays which impart a good bubble structure tend to reduce fishscaling. (6) Cold-working the metal surface reduces the tendency of fishscales to form. (7) Hydrogen is the gas which forms at the metal-enamel interface and causes fishscales to form.

Infra-Red Heating in Industrial Processing. E. E. Halls. (Metal Treatment, 1942, vol. 9, Winter Issue, pp. 159–166). Heating by radiation with infra-red rays has been successfully employed in the United States for about ten years, but has received little attention in Great Britain. In this paper the author surveys the process and discusses the principles, equipment, applications and advantages. The process was at first used for baking organic finishes on automobiles, and it has been developed to include the finishing of white enamel on refrigerator compounds, the stoving

of coloured enamel finishes on office furniture, the finishing of cash register parts, outdoor automatic machines and advertisement signs, and for the rapid drying of electro-plated parts as they leave the plating line. The lamps used are gas-filled bulbs having either tungsten or carbon filaments, designed to operate at between 2200° and 2500° K. The life of a lamp is of the order of 10,000 hr. Lamp-reflector assemblies are marketed in units consisting of groupings of a number of assemblies in circular formation or in channel form. In the infra-red system the whole of the energy can be used for the thermal process in question, provided that plants are designed with this in view. The approach to 100% efficiency is close if automatic control of the heat source is linked with the passage of the work through the chamber or heating unit, so that when any gaps occur in the work line the power is immediately shut off.

Some Surface-Treatment Problems in War Time. B. Steffenburg. (Teknisk Tidskrift, 1942, vol. 72, Apr. 4, pp. 51–54). (In Swedish). The author reviews some methods which have been adopted in Sweden for the protective coating of steel, zinc and wood, having regard to the difficulty in obtaining certain raw materials. A brief description of the Pahl method of spraying a molten resin on steel is given. The wax, in cylindrical solid form, is put in the pistol which is provided with an electric heating element to bring it up to its melting point of about 150° C. The molten wax is projected in droplets by compressed air against the steel surface, which has been dried and slightly preheated by an acetylene flame from the same pistol. A layer of compressed air projected through an annular nozzle prevents the acetylene flame from coming in contact with the wax. No solvent is required for the process. If the steel surface is prepared by sand-blasting, the protection against corrosion offered by the wax coating is excellent, as has been shown by 5-year tests at the Berlin-Dahlem testing station.

PROPERTIES AND TESTS

(Continued from pp. 135 A–141 A)

The Stress-Strain Curve for Steel Specimens between the Upper and Lower Yield Points. W. Weibull. (Jernkontorets Annaler, 1942, vol. 126, No. 8, pp. 333–357). (In Swedish). The author describes a special tensile-testing machine with which accurate stress-strain curves could be obtained for the elongation of the specimen between the upper and lower yield points. Specimens 80 mm. long × 5 mm. in dia. were used. The specimen passed through a slot in a wedge-shaped block which moved between the two specimen-carrier blocks. At the face of one carrier block two pairs of quartz crystals with a combined bearing surface of

2000 sq. mm. were arranged. The crystals were connected with a valve, an amplifier and an oscillograph. Tensile stress was applied to the specimen by an electric motor connected by worm-gearing to the wedge, and the movement of the wedge was mechanically linked to the drum moving the oscillograph chart. With this apparatus curves were obtained in which 1 mm. on the ordinates represented a stress of 0·429 kg. per sq. mm. and 1 mm. on the abscissae represented an elongation of $1{\cdot}31 \times 10^{-3}$ mm.

Stress-strain curves for three steels containing carbon 0·04%, 0·12% and 0·51% respectively, at three different rates of strain are presented. From a study of these it is seen that the rate at which the stress decreases is directly proportional to the elongation rate, but the difference between the upper and lower yield points does not depend on the rate of elongation, neither is there any correlation between the upper and lower yield points.

Internal Stress of Metals. C. A. Wilkins. (Metallurgia, 1943, vol. 27, Jan., pp. 115–117, 120). The author discusses theories relating to the formation and nature of internal stresses in metals and describes methods of measuring them. Internal stresses of large magnitude can be set up in metals during heat treatment, and these can be accentuated or decreased by various factors, such as machining conditions and the shape of the part. In forgings, the expansion due to the formation of martensite and the contraction due to hot upsetting are probably of the greatest importance when quenching, but the shape of the part and the conditions during heating and cooling all tend to modify the net result. Although non-destructive X-ray methods of measuring internal stress have been introduced with mixed success, a sensitive non-destructive method has not yet been found, and the author suggests that tests might be based on either accurate e.m.f. measurements, or on the magnetic permeability of the metals.

Plastic Deformation of Metals under Stress. A. Markin. (Australian Institute of Metals: Australasian Engineer, 1942, vol. 42, Dec. 7, pp. 9–11, 45–55). The author surveys the theories concerning the plastic deformation of metals and its effect on their physical properties, and discusses the application of plastic working in industry. The mechanical properties of a metal sensitive to changes in structure and the changes in most of the individual properties produced by cold deformation are closely related to each other. The rate and extent of strain-hardening vary appreciably for the different metals and alloys. The reduction of area is decreased more rapidly by drawing than by rolling, and light rolling may even produce a small increase in this value. Cold-work considerably increases the fatigue strength of steel, particularly so if it is followed by annealing. The cold-deformation accompanying the fatigue process itself affects the fatigue strength in a manner depending on whether the stress is below or above the fatigue limit. Low-stress cycles increase and high-stress cycles

reduce the fatigue strength. The creep properties of metals are adversely affected by cold work. The retarding effect of strain-hardening on creep is observed up to a certain temperature when the load is applied for a long time. Above a critical temperature a cold-worked metal creeps faster than an annealed metal. The degree of strain-hardening of a coarse-grained, and therefore softer, metal for a given reduction is less than the hardening of a fine-grained one. The velocity of deformation does not appreciably affect the degree of strain hardening. The tendency of soft steel sheet to form stretcher strains increases with an increasing rate of deformation; slow starting speeds are therefore desirable for the deep-drawing of soft steel.

Fatigue Strength of Commercial Butt Welds in Carbon-Steel Plates. W. M. Wilson. (Welding Journal, 1942, vol. 21, Oct., pp. 491-S–496-S). The author reports the results of a comprehensive series of fatigue tests on butt-welded specimens of $\frac{7}{8}$-in. rolled steel plate; the object was to determine what fatigue strength values should be inserted in specifications for butt welds in welded structures. The following conclusions were arrived at: (1) The fatigue strength was about 50% greater for failure at 100,000 cycles than at 2,000,000 cycles; (2) the fatigue strength was about 50% greater when the stress range was from zero to a maximum tension than for a range from a maximum tension to an equal compression value; (3) the fatigue strength for failure at 2,000,000 cycles with a stress range from maximum tension to 50% of this tension equalled or exceeded the yield point of the material and is therefore not important to the engineer; (4) machining off the re-enforcement flush with the base plate increased the fatigue strength of the welded joint by a significant amount; (5) the variations in the quality of the weld resulting from variations in the skill of the operator were greater than those resulting from the use of different electrodes; (6) the fatigue test is a searching one and will reveal flaws in welds that pass the standard static tension test; and (7) the common flaws that cause a low fatigue strength in butt welds, in order of importance, are: Lack of fusion of the base plate, especially at the root of the weld; slag inclusions; and blow-holes.

Strength of Steel Subjected to Biaxial Fatigue Stresses. J. Marin. (Welding Journal, 1942, vol. 21, Nov., pp. 554-S–559-S). The author describes a testing machine which was developed to enable biaxial fatigue stresses to be applied simultaneously to tubular steel specimens, the object being to obtain data on the fatigue strength of metals subjected to combined stresses. The specimens were $6\frac{1}{2}$ in. long with an inside diameter of 1 in., the wall thickness was 0·050 in. at the thinnest part in the centre; they had flanges and screwed spigots at the ends to take an oil plunger in one end and a link to a rocking lever at the other end. A single electric motor was arranged to drive two eccentrics, one

of which operated the rocking lever so as to apply a longitudinal fluctuating load, the other operated the oil plunger so as to cause a fluctuating pressure of oil on the internal walls of the specimen. The load and oil-pressure ranges could be controlled. The motor speed and gearing were designed to produce 200 load cycles per min. The results of some preliminary tests on a 0·20% carbon steel are given, but sufficient data have not yet been obtained for any conclusions to be drawn.

How to Use Hardness Tests. T. H. Gray. (Machinist, 1943, vol. 86, Jan. 16, pp. 1075–1078). The author explains how indentation hardness tests can be used to detect surface decarburisation and case depth, and discusses the possible causes of insufficient hardness and " soft spots " in heat-treated steel.

Effect of Moderate Cold-Rolling on the Hardness of the Surface Layer of 0·34-percent-Carbon Steel Plates. H. K. Herschman. (Journal of Research of the National Bureau of Standards, 1942, vol. 29, July, pp. 57–67). The author reports on an investigation of the changes caused by cold-rolling in the hardness of specimens of steel plate, measuring $4\frac{1}{2} \times 1 \times \frac{1}{4}$ in. and containing carbon 0·34%. The surface of the specimens was initially surface-finishing by three different methods—grinding, buffing and metallographic polishing. After rolling, hardness tests were made with Knoop and Rockwell indenters. The Knoop hardness number of the surface layer of the steel was lower after cold-rolling reductions of 1% and 2% than it was prior to rolling. The results with the Rockwell tester in no case revealed a lower hardness after cold-rolling. The Knoop readings obtained suggest that the most significant hardness decreases which accompanied the lighter degrees of rolling (reductions of 1% and 2%) occurred in a layer less than 0·0003 in. thick.

Jominy End-Quench Hardenability Tests on Carbon-Manganese Steels. G. A. Timmons. (Welding Journal, 1942, vol. 21, Oct., pp. 467-S–476-S). The author reports the results of end-quench hardenability tests carried out by the Climax Molybdenum Co. on five manganese steels (in the range carbon 0·25% to 0·37%, manganese 0·38% to 1·45%) the results of which were to be correlated with data obtained by other workers investigating the weldability of similar steels (*see* p. 167 A). Curves are presented showing the increase in hardness obtained when the steels were quenched from 1700°, 2100° and 2350° F. The results obtained were not always consistent, but essentially the steels behaved in a manner which could be predicted from a knowledge of the composition and grain size. In order to correlate the quantitative data obtained from end-quench tests it would be necessary to determine the cooling rates of the specimens at various locations when the temperatures from which they were quenched were increased, and then to determine the cooling rates in the heat-affected zone of the particular weld under consideration. The microstructures produced in end-quenched specimens should be examined in order to deter-

mine the grain sizes developed after quenching from various temperatures; from such an examination the general characteristics and properties of the microconstituents which are likely to be found in the heat-affected zone of welds in similar steel could be predicted.

The Effect of Welding on the Shear and Hardness Properties of Mild Steel Bars. W. D. Lewis. (Welding Journal, 1942, vol. 21, Nov., pp. 559-S–561-S). The author reports the results of hardness and shear strength tests on welded round bars of 0·20% carbon steel in the as-rolled state and after different forms of heat treatment. Graphs are presented of the changes in hardness and shear strength with increasing distance from the centre of the weld. The maximum shear strength and hardness values were obtained after oil-quenching from 900° to 920° C. Good machining and low hardness values were obtained after cooling in air from 900° to 920° C.

Ageing Phenomena in Steel. N. G. Fraser. (Australian Institute of Metals: Australasian Engineer, 1942, vol. 42, Nov. 7, pp. 177–179). The author discusses the ageing of steel. Straining low-carbon steel gives rise to two effects: (1) The increase in hardness which accompanies cold-working in even the purest single-phase metal, and (2) the increase in hardness by the precipitation or dispersion of another phase induced by the straining. The increase in hardness with ageing is the result of a precipitation phenomenon, since its manifestations are, on the whole, similar to those of ordinary quench-ageing, and also because it has been found to depend to a large extent on the presence of the same constituents as are generally believed to be responsible for quench-ageing. Carbon, nitrogen and oxygen have an appreciable solubility in α-iron at just below the Ar_1 point, but are much less soluble at room temperature so that, if the amount of any of these elements present exceeds the limit of solubility at room temperature, precipitation and ageing can occur. If, in manufacturing a deep-drawn article, the drawing is carried out in several successive stages, the stages should follow one another without interruption, for it is not generally recognised that the heat generated in the steel in any one operation may be sufficient to reduce to perhaps one hour the time for the ageing process to be completed.

On the Cause of High Permeability of Alloys Fe-Si-Al ("Sendust"). A. S. Zaimovsky and I. P. Selissky. (Journal of Physics, U.S.S.R., 1941, vol. 4, No. 6, pp. 563–565). The authors determined the magnetic permeability of ninety iron-silicon-aluminium alloys with compositions in the range silicon 2% to 15% and aluminium 2% to 13% and found that their high permeability was closely related to low magnetostriction and low magnetic anisotropy constants.

High Permeability and Superstructure in Fe-Si-Al Alloys "Sendust" Type. I. P. Selissky. (Journal of Physics, U.S.S.R., 1941, vol. 4, No. 6, pp. 567–568). The author investigated the

influence of heat treatment on the magnetic properties of two iron-silicon-aluminium alloys (aluminium 5·03% and 5·43%, silicon 9·8% and 9·38% respectively). These alloys probably contain superstructures of the type $Fe_3(Al,Si)$. Rapid cooling caused a partial disorder which promoted an increase in the magnetic permeability.

Compacted Magnets with a Synthetic Resin Binder. H. Dehler. (Stahl und Eisen, 1942, vol. 62, Nov. 19, pp. 983–986). Permanent magnets of cast iron-nickel-aluminium alloys are brittle, and as hard as glass; they can only be ground, and it is very difficult to cast them with small holes. In this paper the author describes a process, patented by M. Baermann, by which these magnets can be made from the crushed and finely powdered alloy by pressing at a temperature below the sintering point, using a synthetic resin binder. The compacts can be made with small holes or with studs in them. The magnetic properties of the magnets made in this way have about 20% of the value of those of cast magnets. The process can be applied with advantage to the mass production of magnets.

Substitute Metals. S. C. Johnson. (Australian Institute of Metals: Australasian Engineer, 1942, vol. 42, Nov. 7, pp. 181–191). The author reviews developments in the manufacture and application of carbon and low-alloy steels as substitutes for steels containing higher proportions of alloying elements which are difficult to obtain. The microstructure which will produce the maximum ductility at high hardness is the one which, whether tempered or not, is uniformly free from transformation products, in particular, from ferrite. To achieve this, the work should be heated long enough and at a temperature sufficiently high to obtain austenite of a high degree of uniformity, and it should then be quenched fast enough to prevent any excess ferrite moving into the grain boundaries. The properties of steels to British Standard No. 970 and of the American N.E. (National Emergency) steels are discussed and reference is made to the German claim to be using nitrogen as a substitute for nickel in certain steels in the proportion of 0·15% of the former to 3% or 4% of the latter. The question of replacing some of the nickel in low-nickel steels by copper is controversial and requires further research. Manganese is being used in some cast steels to replace nickel in low-alloy cast steels. Copper in cast steels increases the tensile and yield strengths; the optimum amount of copper varies between 1% and 2%. A process of impregnating steels with silicon has been developed; this involves heating the part in an atmosphere of silicon tetrachloride formed by passing chlorine into a chamber in which the part is embedded in silicon carbide or ferro-silicon. After 2 hr. at 1700–1850° F., a case depth of about 0·030 in. containing 14% of silicon is obtained. This process may be applied to mild steel and malleable cast iron; the case produced resists both wear and corrosion.

The National Emergency Steel Compositions. C. M. Parker. (A.S.T.M. Bulletin, 1942, Aug., pp. 36–41). This was the author's contribution to a discussion on Alternate Alloy Steels and Conservation of Strategic Alloys. He presents data on the properties of many of the National Emergency Steels.

Application of N.E. Steels. M. J. R. Morris. (A.S.T.M. Bulletin, 1942, Aug., pp. 41–43). In this contribution to a discussion on Alternate Alloy Steels and Conservation of Strategic Alloys the author discusses the properties and applications of some of the case-hardening qualities of the National Emergency Steels.

Gearmaker Reports on Successful Applications of N.E. (National Emergency) Alloy Steels. E. J. Wellauer. (American Gear Manufacturers' Association : Steel, 1942, vol. 111, Nov. 16, pp. 106–107, 129–135). The author presents and discusses data on the hardenability of some of the new National Emergency steels which show, in particular, that a low-alloy manganese-chromium-molybdenum steel can be successfully used for making gears and pinions.

The Application and Testing of Steels for Use at Low Temperatures. H. J. Wiester. (Stahl und Eisen, 1943, vol. 63, Jan. 21, pp. 41–47 ; Jan. 28, pp. 64–68). The author reports the results of an investigation of the changes in the mechanical properties of alloy steels at temperatures of + 20° and – 180° C. The steels tested were two non-ageing unalloyed steels, several low-alloy steels containing chromium with nickel, chromium with molybdenum, chromium with manganese, chromium with vanadium, and chromium with aluminium, as well as austenitic chromium-nickel and chromium-manganese steels. The shape of the specimen has an important effect on the impact-test results, and the notch 3 mm. deep with a radius of 1 mm. in the DVM specimens measuring 55 × 10 × 10 mm. is much too severe to represent conditions arising in practice. The specimen proposed by H. Bennek is suggested ; this measures 55 × 10 × 8 mm. with a notch 4 mm. deep and a radius of 4 mm. The metallurgical history and the heat treatment of the steel have an important effect on its behaviour at low temperatures. The selected composition of an alloy steel should be such that sufficient core strength is obtained together with the required case depth and hardness. Steels with a tendency to temper brittleness should be drastically quenched after tempering. The finest possible grain size is desirable. It is advisable to use a strong deoxidising agent (*e.g.*, aluminium) when making steel for use at low temperatures, as this lowers the ageing tendency. Basic Bessemer steel has a strong ageing tendency, and should not be used in low-temperature plant. There is no difficulty in selecting a steel with adequate impact strength at – 75° C. At – 180° C., however, it is not possible to get an unalloyed steel with a satisfactory impact strength even when Bennek's specimen is used, whilst there is no difficulty with a number of alloy steels. Low-

alloy steels containing neither nickel nor molybdenum will, after careful heat treatment, give almost as good impact-test results as the previously preferred steels containing these elements. Sufficient impact resistance at the temperature of liquid air can only be obtained with austenitic steels, and in this class the chromium-manganese and high manganese types are just as good as the chromium-nickel and nickel steels.

The Strength Properties of Heat-Treated Chromium-Manganese Case-Hardening Steels. A. Krisch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung: Stahl und Eisen, 1943, vol. 63, Jan. 28, pp. 61–64). The author reports on an investigation to determine whether the German low-alloy case-hardening steels EC 80 and EC 100 could also be used after heat treatment as high-strength steels. The steels contain small amounts of chromium, nickel and molybdenum. Specimens were prepared by quenching in water and tempering at 220° C. It was found very difficult to heat-treat them to give a specific range of mechanical properties, as the strength was governed by the quenching, not by the tempering. With steel EC 100 a tensile strength of over 140 kg. per sq. mm. and high impact values could be obtained.

Alloy Cast Irons. E. Cozens. (Machine Shop Magazine, 1943, vol. 4, Feb., pp. 51–54). The author discusses the properties of alloy cast irons giving examples of their application in engineering shops. Chromite and Meehanite are dealt with in particular. The former is a chromium-nickel cast iron with good heat-resisting properties; it is frequently used for pack-carburising boxes and annealing boxes, as it does not distort much.

D.T.D. 126A.—A Useful Carbon-Manganese Steel. B. Thomas. (Metallurgia, 1943, vol. 27, Jan., pp. 87–88). The author discusses the properties of steel to Air Ministry Specification D.T.D. 126A; this has a tensile strength of 40–55 tons per sq. in. and contains carbon 0·30% max., manganese 1·75% max., and it may contain up to 0·20% of nickel; it is used for drop stampings and forgings. The most suitable quenching temperature for the heat treatment is 870° C. When the parts are from $\frac{1}{2}$ in. to $\frac{5}{8}$ in. thick, it may be possible to adopt the lower figure of 850° C. Although some critics may say that 20° C. difference is too small to bother about, the author suggests that for a plant handling say 50 tons per day of quenched work, the difference in heat dissipation required of already heavily overburdened oil-quenching equipment by this reduced temperature, with the specific heat of steel taken as 0·16, is very considerable, quite apart from the waste of fuel in maintaining a furnace at 870° when only 850° C. is necessary.

Cast Steel Tire Cuts Maintenance Costs. H. H. Blosjo. (American Foundryman, 1942, vol. 4, Nov., pp. 2–4). The author describes and illustrates a new type of cast-steel tyre for Diesel locomotives. The wheel consists of three castings of high-carbon steel, comprising the tyre and two retainer castings, one of them

integral with the hub. Between the retainer castings and the tyre are mounted two preformed rubber insulators, the whole assembly being held by twelve bolts, which makes the replacement of a worn tyre a simple matter.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 142 A–143 A)

Industrial Research in Great Britain. P. Dunsheath. (Royal Society of Arts: Foundry Trade Journal, 1943, vol. 69, Feb. 11, pp. 111–114). The author discusses the organisation of industrial research in Great Britain, giving information on the expenditure and activities of research associations. The publication of the results of research and the obtaining of patents are also dealt with. To bring science and industry in still closer contact there should be set up means for the cross-fertilisation of ideas. A live central co-ordinating secretariat is suggested to maintain a comprehensive record of all researches in progress and completed; it might also have powers to maintain secrecy at certain stages of an investigation in the interest of originating members, and decide when, in the public interest, publication is desirable.

Investigations with the Supermicroscope of the Structure of Unalloyed Steels. H. Mahl and F. Pawlek. (Archiv für das Eisenhüttenwesen, 1942, vol. 16, Dec., pp. 219–222). The authors present and compare micrographs of the structure of nine heat-treated plain carbon steels containing from 0·35% to 1·62% of carbon, pictures of the same areas of the specimens being obtained at up to 10,000 diameters with an electron-microscope and an optical microscope. With an air-cooled steel the electron-microscope was markedly superior in resolving the minute islands of pearlite. In the case of eutectoid and hypereutectoid steels, the structure resulting from the decomposition of the austenite, which could not be resolved by the optical microscope, was revealed as a more or less well-developed fine pearlitic structure by the electron microscope. Micrographs of the martensitic structure by the two methods were very similar, although the subdivision of the needle-like crystals was shown up better by the electron-microscope technique. The troostite produced by quenching in water from 1100° C. did not have the expected pearlitic structure, but only showed indications that pearlite was beginning to form.

Investigations with the Supermicroscope of Martensite in 0·24% Carbon Steel at Different Degrees of Temper. Edith Semmler-Alter. (Archiv für das Eisenhüttenwesen, 1942, vol. 16, Dec., pp. 223–225). The authoress gives an account of an investigation of the changes in structure of a hardened 0·24% carbon steel brought

about by tempering at various temperatures in the 200–920° C. range. Magnifications of about 4000 to 4500 were obtained by electron-optical methods using transparent colloidal films and, by subsequent enlargement, micrographs at 10,000 diameters were obtained; these were supplemented by oblique projection back-reflection pictures at 7000 diameters. The definition obtained exceeded by far that obtained by the optical microscope at 1000 diameters. The technique for preparing the films and removing them from the specimens is given in detail and several of the micrographs are reproduced.

A Scanning Electron Microscope. V. K. Zworykin, J. Hillier and R. L. Snyder. (A.S.T.M. Bulletin, 1942, Aug., pp. 15–23). The authors describe the development, in the laboratories of the Radio Corporation of America, of a scanning electron microscope with which the surface of opaque materials can be examined. The essential features of the equipment are: (*a*) A heated tungsten wire as the light source; (*b*) four electrostatic lenses through which the electron beam passes to the surface under examination; (*c*) a fluorescent screen which catches the secondary electrons reflected from the surface and produces an optical image which is scanned magnetically. Some micrograms of the surface of nickel, brass and Bakelite reproduced by this apparatus are presented.

The State of the Carbon in Tempered Steel. M. Arbusow and G. Kurdjumow. (Journal of Physics, U.S.S.R., 1941, vol. 5, No. 2–3, pp. 101–108). The authors report the results of an X-ray investigation of the carbon-rich phase which is precipitated on tempering steel at temperatures in the 130–300° C. range. Specimens of 1·4% carbon steel were used which had a regular martensitic structure formed by the quenching of a single austenite crystal. The X-ray pictures revealed interference lines of a carbide which was not Fe_3C. On tempering in the 300–380° C. range this new carbide is converted to Fe_3C. The steel tempered in the 130–300° C. range consists of a heterogeneous mixture of the α-phase supersaturated with carbon and an unknown carbide.

Method of Recording Macro-Structures. G. A. Cottell. (Engineering, 1943, vol. 155, Jan. 29, pp. 81–83). The author describes a technique for producing contact ink impressions of macrostructures on a transparent support; these have the advantage over sulphur prints in that they can be enlarged by projection to about six diameters; the impression is capable of recording much finer detail than that obtained on glossy art paper.

Effect of the Alloying-Element Content and the Testing Conditions on the $\gamma \rightarrow \alpha$ Transformation in the Cold-Deformation of Austenitic Steels. K. Mathieu. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung: Archiv für das Eisenhüttenwesen, 1942, vol. 16, Dec., pp. 215–218). The author reports the results of investigations of the degree of $\gamma \rightarrow \alpha$ transformation caused by the cold-deformation of three types of austenitic steel,

namely: (1) 18/8 steels, some containing titanium; (2) steels containing manganese 16–18% and chromium 1–12%, some with nitrogen additions; and (3) steels containing manganese 12–17%. Specimens 5 mm. in dia. with a 50-mm. gauge length were deformed by one of three methods, *i.e.*, drawing through a die, rolling, and pulling, to give elongations increasing in stages of 5% until fracture. The gauge lengths were then cut into 15 pieces each 3 mm. long the specific magnetic saturation of which was determined in a magnetic balance; this value varies directly with the amount of α-phase. In general, the amount of α-phase increased with increasing deformation, the amount of the increase after small deformations being less than after heavy deformations. After very severe deformation there was often a decrease in the magnetic saturation which was probably due to temperature changes. Above a certain temperature the austenite remained stable, with decreasing temperature the stability was reduced. The heat developed by the deformation had a marked effect on the decomposition of the austenite.

Influence of Initial Structure and Rate of Heating on the Austenitic Grain Size of 0·5-percent-Carbon Steels and Iron-Carbon Alloy. T. G. Digges and S. J. Rosenberg. (Journal of Research of the National Bureau of Standards, 1942, vol. 29, July, pp. 33–40). The authors report on an investigation of the influence of the initial structure and the rate of heating through the transformation temperature range on the grain sizes at 1475° and 1600° F. of a high-purity iron-carbon alloy and two commercial steels each containing carbon 0·5%. The iron-carbon alloy contained 0·5% of carbon and less than 0·031% of identifiable impurities. The two steels were treated to give initial structures differing in the interlamellar spacing of pearlite, or in the form and distribution of the carbides. Variations in initial structure had no effect on the grain size of the iron-carbon alloy. Although the initial structure had some influence on the grain size of the steels, no correlation was found between the grain size and the spacing of the pearlite. The rate of heating had a pronounced effect on the grain size of the iron-carbon alloy, and, in some cases, on the grain size of the steels. The trend in the steels was the reverse of that in the alloy in that the finest grains were obtained in the steels with slow rates of heating. A large number of the micrographs of the structures obtained are reproduced. (*See* p. 108 A.)

CORROSION OF IRON AND STEEL

(Continued from pp. 111 A–112 A)

Maintenance of Colliery Wire Ropes. A. E. McClelland. (Manchester Geological and Mining Society: Colliery Guardian, 1943, vol. 166, Feb. 5, pp. 153–159; Iron and Coal Trades Review,

1943, vol. 146, Jan. 29, pp. 152–153). The author draws attention to the main causes of deterioration of winding and haulage ropes as disclosed by investigations of the Safety in Mines Research Board. Corrosion-fatigue is the most troublesome and widespread form of deterioration. As seen by the naked eye, the fractures from this cause are similar to dry fatigue fractures, but the microscope reveals numerous corroded side cracks. The use of galvanised wire, improving the lubrication, preventing the access of moisture and reducing repeated stressing by any means which will give a smoother wind are methods of combating corrosion-fatigue.

Electrolytic Protection of Water Systems. P. S. Armstrong. (Iron and Steel Engineer, 1942, vol. 19, Oct., pp. 34–39). The author reports and discusses the results of several series of tests with the cathodic protection of water-tanks to ascertain its effect on the water in the tank. It was found that the cathodic protection of tanks storing boiler feed water is a practical and economic proposition. The treatment of the water for boiler purposes is not obviated by installing a cathodic protection system, although such troublesome elements as iron and manganese may be removed by it.

What Effect Has the Air Content of the Water on Cavitation and Corrosion? I. Vuškovic. (Escher Wyss Mitteilungen: Teknisk Tidskrift, 1942, vol. 72, Feb. 21, pp. 20–24; Mar. 21, pp. 32–35). (In Swedish). The author reports on an investigation of the factors affecting the cavitation of turbine blades. An apparatus was set up with which the changes in the air content of the water with changes in degree of vacuum could be followed. A stroboscope was used to establish the point at which the air began to separate out from the water. The stroboscope revealed that air separated out first in the form of a scum of bubbles of microscopic size, the steam separated out later, quite suddenly, when a certain critical degree of vacuum was reached, and this point marked the beginning of cavitation. An increase in the amount of air in the water caused a decrease in the cavitation corrosion. This can only be explained by the theory which Föttinger put forward in 1926, namely, that the undissolved air acts as a cushion when the bubbles containing air and steam collapse.

Solubility of Steels in Lead and Lead Alloys. W. Timmerhoff. (Zeitschrift für Metallkunde: Metal Treatment, 1942, vol. 9, Winter Issue, pp. 187–188). **Solubility of Steels in Molten Lead.** W. Timmerhof. (Iron and Coal Trades Review, 1943, vol. 146, Jan. 22, pp. 129, 132). The author gives an account of some tests of the solubility of Armco iron and of steel rods in molten lead, molten antimony and lead, tin and antimony alloys at temperatures exceeding 500° C. After 2 hr. in molten antimony at 650° C. all rods were heavily attacked. After 7 days in a melt of lead plus 8% of antimony at 500° C. the samples acquired a lead coating in places, whereas at higher temperatures, a thin coat of lead was found spread over the whole surface. In the next test, samples

were rotated for $2\frac{1}{2}$ days in melts at 600° and 750° C. and the attack was much greater than when the rods were stationary. In the final test, samples were suspended in a melt of lead with 8% of tin for $2\frac{1}{2}$ days. At 450° and 600° C. the samples were covered with a thin lead coating. A section of Armco iron after immersion at 450° C. showed slight attack in places.

BOOK NOTICE

(Continued from pp. 146 A–147 A)

Biringuccio, V. "*The Pirotechnia of Vannochio Biringuccio.*" Translated from the Italian with an Introduction and Notes by Cyril Stanley Smith and Martha Teach Gnudi. (Publication sponsored by the Seeley W. Mudd Memorial Fund). 8vo. pp. xxvi + 476. Illustrated. New York, 1942: The American Institute of Mining and Metallurgical Engineers. (Price $5).

Biringuccio's "Pirotechnia," the first printed treatise on the whole field of metallurgy, is quoted by most authors on the history of the subject, but almost always at second hand. Although it passed through five Italian editions between its first publication in 1540 and 1678, and it was translated into French, the original work is not often seen, and it never acquired the popularity of Agricola's "De Re Metallica," which followed it in 1556. This famous work is now well known to English-speaking metallurgists through the translation by H. C. and L. Hoover. Biringuccio's work was less attractively printed, and its woodcuts had not the beauty or completeness of those which illustrated Agricola's treatise. Only a few sections have previously been translated into English, and are known through their quotation in the works of Percy and Hoover.

The present edition is the product of a collaboration which sets a pattern for similar undertakings. One of the authors is an authority on Italian literature and the other an expert metallurgist. The result is entirely happy, as both textual and technical accuracy have been ensured. The style, which is consistently maintained throughout, has a faintly archaic flavour which makes pleasant reading. Biringuccio was a craftsman, not a learned scholar, and he wrote with enthusiasm of what he knew at first hand. He had visited many mines in Germany as well as in Italy, and controlled foundries in his own city of Siena and later in Rome.

Earlier writers on metallurgy had given far more attention to what had been said on the subject by Dioscorides and Pliny than to processes which they had seen, and the note of scepticism which is found both in Biringuccio and in Agricola is most refreshing. The Italian author is satirical at the expense of the alchemists and of such learned but superstitious writers as Albertus Magnus. For some reason, however, perhaps because this was a field in which he had less experience, his scepticism deserts him in the chapter on gem stones, in which he repeats, apparently without satirical intention, such old fables as that the only liquid in which the diamond can be cut is the blood of a he-goat which has drunk wine and fed on parsley for several days beforehand. There

are few lapses of this kind, and Biringuccio must be looked upon as an early example of the scientifically minded practical worker, coolly sceptical of all but experience, and in so far a forerunner of the scientific galaxy of the succeeding century. He was not an original thinker, but he deserves the gratitude of metallurgists for having set down so fully the practice of his day in the treatment of ores, in smelting and foundry practice, and in such minor arts as coining and wire-drawing. The section on guns is remarkably full, and the title is further justified by the inclusion of chapters on gunpowder and its various applications.

The printing, in a very beautiful and legible type, does the greatest credit to the Yale University Press. On account of the inadequacy of the original woodcuts, the translators have added a few reproductions of drawings from Agricola and Ercker, which show better the construction of furnaces described in the text. Both bibliography and index are provided. In all, an admirably edited book which deserves the warmest welcome.

C. H. DESCH.

MINERAL RESOURCES

(Continued from pp. 114 A–115 A)

The Iron-Bearing Coastal Sands in Italy. G. Coppa-Zuccari. (Montanistische Rundschau: Teknisk Tidskrift, 1943, vol. 73, Jan. 9, pp. B4–B5). (In Swedish). After briefly reviewing the occurrence and nature of the iron-bearing sands on the Italian coast and previous attempts to exploit them, the author gives an account of the progress made since 1938 by the S.A. Nazionale Cogne with sand on the coast near Nettunia. This sand contains titania and magnetite, as well as ilmenite and zirconia. The sand is first screened into three sizes, and a magnetite concentrate containing about 62% of iron, 3·5% of titanium and 0·12% of vanadium is produced from these by magnetic separation. A method of sintering the concentrate and reducing the sinter in the blast-furnace has been worked out; no details of this are given. Another method has been worked out by the S.A. Breda.

California's Chromite Assumes New Importance. J. B. Huttl. (Engineering and Mining Journal, 1942, vol. 143, Oct., pp. 43–46). The author gives a brief account of the occurrence of chromium ores in California, with some details of the concentration plants of the Rustless Mining Corporation.

The Mineral Resources of Northern Rhodesia. T. Deans. (Bulletin of the Imperial Institute, 1942, vol. 40, No. 4, pp. 295–306). The author gives an account of the development of the mineral resources of Northern Rhodesia. The total value of the minerals produced has risen from £3,000,000 in 1924 to £66,000,000 in 1939. Copper ores easily take first place in production. The Nkana copper mine also produces important quantities of cobalt, the ore containing 0·02–0·5% of cobalt in the form of the sulphide carrollite. Tungsten occurs, but not in economic quantities. There are some manganese deposits, but they appear to be of low grade, and are not very extensive. Deposits of high-grade hematite and magnetite also occur; their extent is not known, and it is unlikely that an iron industry will ever be established.

ORES—MINING AND TREATMENT

(Continued from pp. 115 A–116 A)

Technical and Economic Aspects of Ore Concentration, Selecting the Method of Crushing, and the Factors Related Therewith. S. Mörtsell. (Teknisk Tidskrift, 1942, vol. 72, Oct. 10, Bergsvetenskap pp. 77–82). (In Swedish). The author discusses how the following

factors affect the crushing and concentration of ores: (1) The proportion of fines; (2) the granite in the ore as mined; (3) the way different qualities of ores are mixed in the ore as mined; (4) woody substances in the ore; (5) fatty or oily substances in the ore; and (6) oxidation during continued storage at the crushing plant. The manner in which crushing problems have been dealt with by Bolidens Aktiebolag, which refines sulphide ores, is explained.

Beneficiation of Scheelite Ores by Gravity Concentration. E. H. Burdick. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1534: Mining Technology, 1942, vol. 6, Nov.). The author discusses the methods of concentrating scheelite ore containing from 0·4% to 1·0% of tungstic oxide.

Survey of the Iron Ore, Pig Iron and Scrap Situation. M. D. Harbaugh. (Iron and Steel Engineer, 1942, vol. 19, Nov., pp. 26–29). The author surveys the changes brought about in the demand and production of iron ore, pig iron and scrap in the United States owing to war conditions. The ore situation is such that the mining industry is giving immediate consideration to plans for an undertaking that it had not expected to have to deal with seriously for another 10 or 15 years, namely, the production of high-grade ore by the large-scale concentration of the iron-bearing rock (the taconites) of the Lake Superior ranges; this rock, which contains 25–30% of iron and twice as much silica, occurs in practically unlimited quantity. By 1941, pig iron and scrap consumption had risen to 35 and 37½ million tons respectively. Despite publicity and political promotion, it does not appear that sponge iron will contribute anything to the metal shortage.

2400 Tons of Sinter per Day. (Iron Age, 1942, vol. 150, Dec. 31, pp. 32–35). An illustrated description is given of a modern sintering plant at the Campbell Works of the Youngstown Sheet and Tube Co. Ore fines, flue dust, coke breeze and scale are the raw materials. There are two sintering machines, with a separate feeder system for each on opposite sides of the storage bins. By discharging from two or more bins and controlling the flow of material, any proportion of each material can be obtained in the sinter mix. The sintering machines are about 87 ft. long with grates 72 in. wide. The charge is deposited from a swinging chute on to the pans, which pass along a conveyor under the igniter; this consists of a line of coke-oven-gas burners supplied with air at high pressure. Suction is applied by twelve wind-boxes underneath the pans. The two fans producing the draft for the system have a capacity of 140,000 cu. ft. of air per min. at a 25-in. static head. There are sixty electric motors on the whole plant, and all the main ones are controlled at one central point.

Briquetting Machine Supplies Charge and Feed Ore in Cubes. J. D. Knox. (Steel, 1943, vol. 112, Jan. 11, pp. 82–86). The

author describes a briquetting plant which is being successfully used at a Pittsburgh steel plant for pressing fine ores into 4 × 4 × 4 in. briquettes suitable for charging into open-hearth furnaces. At the rear of the machine is a hopper for measuring the amount of ore for each batch. The ore passes from this into a power-driven mixer where a binder and the desired amount of moisture are added. The aggregate is then discharged into a storage bin, beneath which is a measuring device and a feeder-box. In the bottom of the latter are four openings, 4 × 4 in. in section, through which the charge drops into compression chambers. About 2000 lb. per sq. in. pressure is applied by plungers moving upwards. The briquettes weigh from 6 to 7 lb. each, and will pass through the slag layer into the molten steel without disintegrating.

REFRACTORY MATERIALS

(Continued from p. 149 A)

Chromite and Magnesite Refractories. G. E. Seil. (American Ceramic Society: Refractories Journal, 1943, vol. 19, Feb., pp. 39–41). After a brief review of the properties of chromite refractories, the author describes the process of recovering magnesia from sea-water as practised at a plant in San Francisco Bay.

An Investigation of the Permanent Expansion of Silica Products Containing Cristobalite. G. R. Rigby, A. E. Dodd, R. P. White and A. T. Green. (Transactions of the British Ceramic Society, 1943, vol. 42, Feb., pp. 11–16). Although the thermal expansion of unused silica bricks from 20° to 1000° C. is usually completely reversible, it has been observed that heating of the grey zone of some silica bricks which have been used in the roofs of open-hearth furnaces causes permanent growth. Successive reheatings cause successively less growth. Parallel results have been observed with fired saggar mixes containing cristobalite derived from fused silica grog and silica bricks which have been heated at 1600° C. The permanent growth has been attributable to the cristobalite; it occurs between 200° and 500° C., which includes the inversion temperature range of cristobalite, is largely unaffected by the rate of heating, and is diminished by the application of external stress. The $\alpha \longrightarrow \beta$ inversion of the cristobalite is thought to produce stresses tending towards expansion, which, in certain conditions of cristobalite crystal packing and elasticity of the matrix, can give rise to an irreversible growth.

Refractory Materials in Blast Furnaces. G. R. Rigby and A. T. Green. (Journal of the West of Scotland Iron and Steel Institute, 1942–43, vol. 50, Part II., pp. 17–24). The authors discuss refractory materials in blast-furnaces under the following headings:

(1) Causes of failure of the brickwork; (2) properties of bricks for blast-furnace linings; (3) conditions of operating blast-furnaces; and (4) methods of protecting blast-furnace linings. In the throat region above the stock line, a dense brick resistant to abrasion is required. The alumina content of the stack structure should be over 30%, and the bricks should survive 100 hr. exposure to carbon monoxide at 450° C. without any disintegration. There is evidence supporting the view that in the bosh region an aluminous firebrick gives very good results. The hearth brickwork should have high refractoriness-under-load under reducing conditions, low after-contraction and good shape. In the hearth, carbon blocks are probably more satisfactory than any firebrick material. The maximum size of the burden should be controlled, and all fines should be sintered to reduce segregation of the burden. Water-cooling in the bosh region is almost essential, and with most furnaces this water-cooling can be extended with advantage throughout that portion of the stack lining where face temperatures are over 400° C.

Steel-Pouring Refractories in Foundry Practice. R. H. Stone. (Transactions of the American Foundrymen's Association, 1943, vol. 50, Mar., pp. 804–813). The author discusses the design of, and material for, stoppers and nozzles in steel foundry ladles. A reasonable density and medium firing in the manufacture of sleeves give the necessary resistance to slag attack. The stopper is generally made of harder material than the nozzle. For heats of 5 tons and up, special provision should be made for drying stopper-rod assemblies; an economical source of heat for the drying-oven is a box full of slag placed underneath it. The pin for fixing the stopper head to the rod should be of 0·10% max. carbon steel because of the high melting point of this grade.

FUEL

(Continued from pp. 149 A–151 A)

The Elimination of Carryover under Steel Mill Operating Conditions. H. M. Rivers and W. P. Hill. (American Society of Mechanical Engineers; Blast Furnace and Steel Plant, 1942, vol. 30, Oct., pp. 1151–1154). The authors describe measures taken at the boiler plant of the Bethlehem Steel Co. to deal with the excessive carry-over of boiler-water in the steam when increasing load was put on the boiler because of the higher production required from the works. Any increase in the oil/gas ratio in the fuel supplied to boilers fired with oil and blast-furnace gas increased the amount of heat absorbed in the furnace wall tubes, and the most severe surges of carry-over accompanied such changes in firing. The trouble

was cured by fitting larger solid baffles along almost the whole length of the drums, reaching from the top of the drum to several inches below water-level. This alteration was made to other boilers, and the steam purity remained consistently good except at very high ratings and abnormally high water-levels. There was a critical water-level which could not be exceeded without causing severe carry-over.

The Origin and Composition of Coals. R. A. Mott. (Fuel in Science and Practice, 1942, vol. 21, Nov.-Dec., pp. 129–135; 1943, vol. 22, Jan.-Feb., pp. 22–26). There has been lack of agreement in previous studies of the origin of coal seams, probably because geological studies have not taken into account information yielded by a study of the coal itself. The present paper is concerned with the mode of origin of coal seams and the mode of their development in composition. In the course of this study the author suggests how durains originated and developed, particularly in coals of low rank.

The Physical Properties and Physical Structure of Coals. C. G. Cannon. (Journal of the Institute of Fuel, 1942, vol. 16, Dec., pp. 51–60). The author reviews investigations by the methods of modern physics (such as X-ray diffraction) of the optical properties of coals. It is shown that for coals, as for other mixtures, chemical constitution, density and refractive index are closely related. Substances of different chemical constituents and structure give different shaped optical dispersion curves. The fact that coals of varying rank give parallel dispersion curves indicates that the structure of the refracting micellæ changes very little with rank. This conclusion is in agreement with the X-ray evidence for a graphite-like lattice, which also changes very little with rank. The increase of refractive index and density with rank indicates a closer packing of the micellæ as the volatile matter decreases. Mahadevan, and Turner and Anderson, passed a monochromatic beam of X-rays through single chips or flakes of coal samples. Mahadevan found uniform intensity distribution round the haloes from bituminous particles, indicating random orientation of the diffracting particles; while Turner and Anderson found intensity maxima on the haloes from anthracites, indicating preferred orientation. These X-ray results are in complete agreement with the observed optical isotropy of lower-rank coals and optical anisotropy of the anthracitic coals. The refractive index and optical anisotropy might well form the basis for the correlation and classification of coals by structure and rank.

Performance Tests Prove Pulverized Coal Practical and Economical for Small Forge Furnaces. R. B. Engdahl and F. E. Graves. (Heat Treating and Forging, 1942, vol. 28, Dec., pp. 623–626). The authors present data on tests on a furnace for small forgings which had been converted for firing with pulverised coal. Tables and curves of fuel consumption, rates of heating and output are given.

The time required to attain forging temperature was very little more than with oil fuel, and the fuel cost was much less.

Pulverized Coal for Metallurgical Furnaces. R. B. Engdahl. (American Institute of Mining and Metallurgical Engineers: Iron Age, 1942, vol. 150, Dec. 31, pp. 27–31). The author describes applications of pulverised-coal firing to rotary melting furnaces and reheating furnaces. Experimental work is being conducted with the burning of pulverised coal in radiant-tube heat-treatment furnaces, and the results so far are satisfactory; the flow of gases through the tube must be sufficiently rapid to sweep out any fine ash.

The War Production Board's Aid to Industry in Expediting Production of Coke and Pig Iron. S. Weiss. (Chicago District and Eastern States Blast Furnace and Coke Oven Associations: Blast Furnace and Steel Plant, 1942, vol. 30, Nov., pp. 1245–1247). The author explains the steps which have led up to the creation of the War Production Board in the United States in January, 1942, the expansion programme it has put before the iron and steel industry, some of the financial arrangements and the functions of the Raw Materials Section of the Iron and Steel Branch of the Board.

Better Coke for More Pig Iron Production. A. C. Fieldner. (Chicago District and Eastern States Blast Furnace and Coke Oven Associations: Blast Furnace and Steel Plant, 1942, vol. 30, Nov., pp. 1279–1281, 1306, 1307). The author explains the steps taken by the Bureau of Mines and the Office for the Solid Fuels Coordinator for War to appoint an Advisory Committee for Increasing Coke and Iron Production. Visits have already been made to several of the major producers of metallurgical coke. A list is given of the problems more or less common to most of the companies in producing the maximum amount of the best quality of coke for the maximum output of pig iron. The organisation for pooling knowledge on these problems and their solution is discussed.

Carbonisation of Saar and Lorraine Coals. W. Gollmer. (Iron and Coal Trades Review, 1943, vol. 146, Mar. 12, pp. 393–395). An abridged English translation is presented of a paper which appeared in Stahl und Eisen, 1942, vol. 62, Sept. 17, pp. 789–795. (*See* p. 40 A).

The Determination of the Composition of Blends of South African Coals Suitable for the Manufacture of Metallurgical Coke. L. A. Bushell. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1942, vol. 43, Nov.-Dec., pp. 67–88). In South Africa the coking propensity of the coals is not nearly so well developed as in the coals of other countries, and the proportion of non-coking coal which can be used for blending is therefore not so high. A comprehensive account is given of the analysis of many South African coals and blends, of laboratory determinations of their swelling properties, and of box tests carried out in the coke-ovens at the Iscor Works.

Plan to Improve Blast Furnace Coke. W. T. Brown. (Chicago District and Eastern States Blast Furnace and Coke Associations: Blast Furnace and Steel Plant, 1942, vol. 30, Oct., pp. 1137–1145; Nov., pp. 1255–1263). The author surveys the geology and properties of the low-volatile coking coals from the Pocahontas seams Nos. 3, 4 and 5, and from the Beckley, Sewell and Lower Kittanning seams of Pennsylvania and Virginia. The results of expansion tests on these coals and on coal blends are discussed, and suggestions are made for suitable blends, with a view to conserving the best coking coals without detriment to the quality of the metallurgical coke produced.

Blast Furnace Gas Conditioning. O. R. Rice. (Iron and Steel Engineer, 1942, vol. 19, Dec., pp. 66–89). The author surveys the methods of cleaning blast-furnace gas and applications of the cleaned gas. A table shows size analyses and chemical analyses of each size range of dust removed from blast-furnace gas in United States practice. Some boiler plants with water walls and continuous ash disposal are now satisfactorily burning gas direct from the secondary dust-catcher. A dust content of 0·10 grain max. per cu. ft., with the elimination of entrained water, is an adequate specification of cleanliness for boiler gas. There has been a tendency to demand fine-cleaned gas for blast-furnace stoves, but although fine-cleaned gas contains less dust, the proportion of free alkalis in the dust is much higher, and this has caused fusion, slagging and shrinkage of the top checkers. Gas from improved primary cleaners, dry, and with less than 0·10 grain of dust per cu. ft. can be used satisfactorily for soaking pits. Fine-cleaned gas with 0·01 grain, or less, per cu. ft. is a good specification for gas for heating coke-ovens. The advantages and disadvantages of hot-dry cleaning and of cold-wet cleaning are discussed, and dust-catchers, cyclone-cleaners, several types of washing-towers, electric precipitators and sludge-disposal plant are described. Data on the capital and operating costs of gas-cleaning plant are presented.

PRODUCTION OF IRON

(Continued from pp. 151 A–152 A)

Southern Blast Furnace Will Serve Steel Furnaces and Foundries. (Blast Furnace and Steel Plant, 1942, vol. 30, Oct., pp. 1148–1149). Some particulars are given of a blast-furnace, construction of which was completed in May, 1942, for the Republic Steel Corporation in the Southern United States. The hearth is 23 ft. 6 in. in dia., the bosh is 28 ft. in dia. The blast-furnace gas is cleaned by passing it through a dust-catcher, a washer and two electric precipitators. The moisture is removed from the blast in an air-conditioning plant. A battery of 65 coke-ovens is under construction.

Republic's New Blast Furnace is on Production. (Blast Furnace and Steel Plant, 1942, vol. 30, Nov., pp. 1283–1284). Some particulars are given of a blast-furnace recently constructed at the Youngstown plant of the Republic Steel Corporation. It is to produce 1100 tons of pig iron per day.

Bethlehem Relines and Enlarges Blast Furnace in Twenty-One Days. (Blast Furnace and Steel Plant, 1942, vol. 30, Dec., pp. 1395–1396). Some particulars are given of the method employed at the Cambria Plant of the Bethlehem Steel Co. to reline and enlarge one of the blast furnaces. The hearth diameter was increased from 21 ft. to 25 ft., the large bell diameter from 13 ft. 6 in. to 14 ft. 8 in. and the number of tuyères from 12 to 16. The daily output is expected to be raised by 250 tons to 1200 tons of pig iron.

Some Thoughts on the Production of Iron from Ore. R. Durrer. (Teknisk Tidskrift, 1942, vol. 72, Sept. 12, pp. 69–71). (In Swedish). The author discusses the advantages and disadvantages of reducing iron ores using the ordinary blast-furnace, a low-shaft electric furnace, a blast-furnace with oxygen-enriched blast, a rotary furnace, and Wiberg's method of producing sponge iron by reduction with gas. In the low-shaft electric furnace a form of desulphurisation occurs in the gas phase in which the sulphur is driven off as silicon sulphide. Swedish conditions favour the electric furnace because a much smaller quantity of carbon is required and there are no coking coals in Sweden. With oxygen-enriched blast the quantities of blast and of flue gas are less, and the gas is correspondingly richer in carbon monoxide, and therefore has a stronger reducing action; the indirect portion of the total reduction is greater, and the consumption of fuel is therefore less. On the other hand, the temperature drop in the burden is steeper with oxygen-enriched blast, and there is a critical oxygen content at which these opposing effects balance each other; above this critical content the amount of indirect reduction decreases. In Sweden, where charcoal, a high value fuel, is used in the blast-furnace, enriching the blast with oxygen is advantageous only as long as it does not increase the fuel consumption.

Smelting Iron Ores Electrically. H. Cowes. (Iron Age, 1942, vol. 150, Dec. 3, pp. 41–44; Dec. 10, pp. 50–54). The author describes European practice in electric smelting, giving details of the furnace first put into operation at the Spigerwerk plant, Oslo, in 1928, and of the improvements in design by I. Hole and by G. Tysland. The Tysland-Hole furnace is a low one with three electrodes and three charging shafts. The gas velocity is low, so that a large proportion of fine material can be smelted without loss. The temperature of the flue gas is only about 250° C., and arch maintenance costs are therefore very low. The raw materials do not need to have high physical strength because of the low charge height. The carbon used for reduction depends on the material available; a 2 to 1 mixture of coke breeze and coke is suitable; charcoal,

lignite, pea coke and anthracite can also be used. About 8 cwt. of coke are required to produce 1 ton of pig iron. Statistics are given on the operation of four of these furnaces.

The Low-Temperature Gaseous Reduction of a Magnetite. M. C. Udy and C. H. Lorig. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1509 : Metals Technology, 1942, vol. 9, Oct.). The authors describe a laboratory study of the reduction of a magnetite concentrate with hydrogen, from which data were obtained on the effects of changes in bed depth, gas velocity, particle size and temperature. When hydrogen was passed through a heated bed of powdered magnetite the rate of oxygen removal was much less at the top of the bed than at the bottom where the hydrogen entered; the increase in the water-vapour content of the hydrogen passing through the upper part of the bed was not of itself sufficient to account for the very much slower rate of reduction. Calculations were made which suggested that the rate of egress of water vapour from the interior of grains in a packed bed was less than for a loose thin bed. At relatively slow rates of hydrogen flow, the rate of reduction increased with increasing rate of flow until a critical rate of flow was reached above which no increase in the reaction rate occurred. No direct correlation was established between the particle size of the bed of magnetite and the rate of reduction. The percentage reduction after passing hydrogen for 20 min. at different temperatures in the 400–1000° C. range showed that this advanced rapidly at up to 600° C., but from 600° to 700° C. a sharp drop occurred, after which the reduction rate increased again less rapidly than at 400–600° C. The drop between 600° and 700° C. was probably due to the sintering which took place, making it more difficult for the hydrogen to penetrate the bed.

Methods of Improving Stock Distribution. C. M. Squarcy. (Blast Furnace and Steel Plant, 1942, vol. 30, Oct., pp. 1131–1136). The author describes an investigation at the blast-furnaces of the Inland Steel Co., in which the distribution of ore, limestone and coke by the small revolving bell was studied. After each skip-load is dumped, the small bell hopper is automatically rotated through an angle which is a multiple of 60°; this multiple can be controlled by setting a selector. The setting to produce optimum furnace conditions with the desired sequence of skip charges was determined, and this was found to differ for different furnaces.

Efficiency and Consumption Tests with a Blast-Furnace-Gas-Driven Blowing Engine. M. Steffes. (Stahl und Eisen, 1943, vol. 63, Feb. 11, pp. 105–109). The author discusses the improvements in design incorporated in the type DTG 14, 3000-h.p. gas engine, built by Maschinenfabrik Augsburg-Nürnberg, which uses blast-furnace gas for fuel. One of these engines was installed in 1939 at one of the Arbed works to drive the blowers, and the results of some efficiency and consumption tests with it are given.

Some Electrical Supply Aspects of Ferro-Alloy Manufacture. H. A. Sieveking. (Journal of the Institution of Electrical Engineers, 1943, vol. 90, Feb., pp. 65–72). The author discusses the consumption of electricity in the manufacture of ferro-alloys. Some representative consumptions per ton of finished alloy are given, together with statistical information on the quantity of electrically manufactured ferro-alloys over a period of years. This is followed by a description of the type of furnace used, its electrical equipment and details of the electrodes. The proportions of the total costs of producing typical ferro-alloys which are accounted for by the electricity consumption are indicated. It is pointed out that supplies of raw materials are as easily available in Great Britain as they are in the major producing countries, *i.e.*, Norway, Sweden and the United States. A comparison is made of the costs of producing electricity at steam-driven and at hydro-electric generating stations.

Powder Metallurgy. W. D. Jones. (Chemistry and Industry, 1943, vol. 62, Feb. 27, pp. 78–81). The author briefly describes how porous bronzes, hard metal tools, electrical contact points and Alnico magnets are made by the powder-metallurgy process. The example of an oil-pump gear-wheel is cited as one for which the process is particularly advantageous. Processes of chemosorption are considerably influenced by temperature, and release of adsorbed gases together with those in solid solution may even lead to an expansion of the compact during heat treatment. At high temperatures considerable atomic movements bring into prominence the phenomena of diffusion which are responsible for the homogenisation of the polymetallic compacts as well as for the migration of atoms on the surfaces of particles under the influence of surface-tension forces which causes the increasing solidity of compacts with time while being heat-treated. Generally speaking, there is increased sintering activity during the recrystallisation brought about by heating.

Developments in the Production of Hard Metals. H. Wolff. (Teknisk Tidskrift, 1941, vol. 71, Dec. 27, pp. 549–551). (In Swedish). The author reviews the development of the manufacture of very hard alloys containing tungsten by the powder-metallurgy process. Recent developments in Sweden include a process for the mass production of milling-cutters, twist-drills and boring-bits by Aktiebolag Hammarbylampan. In the pressing of cylindrical parts there is more friction between the metal particles near the wall of the die than at the centre, with the result that the density of the pressing increases from the wall to the centre. In the new process, centrifugal force is applied to compress the powder ; this ensures a very high and uniform density.

FOUNDRY PRACTICE

(Continued from pp. 152 A–155 A)

Make Machine Tool Castings in Highly Modern Foundry. P. Dwyer. (Foundry, 1942, vol. 70, Nov., pp. 66–68, 147–149). The author describes the plant and processes at the grey-iron foundry of the Cincinnati Milling Machine Co. At this plant, which is several acres in extent, there are four large cupolas working in pairs on alternate days.

Meets Exacting Requirements for Machine Tool Castings. P. Dwyer. (Foundry, 1942, vol. 70, Dec., pp. 77–78, 161–163). The author concludes his description of the foundry of the Cincinnati Milling Machine Co. (*See* preceding abstract).

The Use of Job Evaluation in the Application of Time Study. E. L. Berry and E. A. Berg. (Transactions of the American Foundrymen's Association, 1943, vol. 50, Mar., pp. 845–851). The authors describe a wages policy for foundries which is based on a combination of (*a*) hourly base rates assessed in relation to skill and technique, and (*b*) an incentive plan.

ArmaSteel—Its Manufacture, Control and Applications. C. F. Joseph. (Proceedings of the Institute of British Foundrymen, 1941–42, vol. 35, pp. 37–53). The author describes the manufacture and properties of ArmaSteel at the Saginaw plant of General Motors Corporation. The name is made up from the critical point Ar and "Ma" for malleable. It is made from a white iron containing carbon 2·65%, silicon 1·35%, manganese 0·40%, sulphur 0·13% and phosphorus 0·05%. The metal is melted in a cupola and refined and superheated in an electric arc furnace. Castings are brought up to about 954° C., held for about 15 hr., cooled to 870° C. and then cooled in air or oil-quenched. The castings have excellent machining properties, high damping capacity, a high resistance to shock at low temperatures, a good response to flame-hardening and local hardening and a high fatigue strength.

Report of the Subcommittee on Sintering Test, Foundry Sand Research Committee, 1941–1942. J. B. Caine. (Transactions of the American Foundrymen's Association, 1943, vol. 50, Mar., pp. 785–800). This paper is a progress report on the work of a subcommittee appointed by the American Foundrymen's Association to study the standard sintering test for moulding sands, details of which were given in a previous paper. The results of some studies with the microscope of grains of Ohio sand at temperatures in the range from the "A" point to the "B" point in the standard test (*see* p. 78 A) are presented.

Seacoal and Fuel Oil in Molding Sand. E. C. Zirzow. (Transactions of the American Foundrymen's Association, 1943, vol. 50,

Mar., pp. 878–890). The author discusses how additions of sea coal and/or fuel oil affect the properties of moulding sands. Sea coal prevents sand from sticking on to castings. If a casting is to be removed from the sand after it has cooled completely, the amount of sea coal required in the sand is less than if the casting is to be removed just after it has solidified. The weight, surface area and cross-section of the casting and the grain size of the sand all have to be taken into account when selecting a suitable sea coal. Oiling the pattern has resulted in smoother casting surfaces, so that adding fuel oil to sand systems has been tried with the same successful results; the amount added varies between 1 quart and 3 gal. per 800 lb. of sand. The most efficient method of adding the oil to the sand system is to make a constant addition at the pug-mill immediately after the final addition of moisture.

A Sand Control Program in a Mechanized Malleable Foundry. D. F. Sawtelle. (Transactions of the American Foundrymen's Association, 1943, vol. 50, Mar., pp. 830–843). The author describes the methods of sand control adopted at the foundry of the Malleable Iron Fittings Co., Branford, a general description of which was recently published by P. Dwyer (*see* p. 45 A).

Lumber for the Patternmaker and Foundryman—Its Grades, Characteristics and the Effect of External Factors. E. T. Kindt. (Transactions of the American Foundrymen's Association, 1943, vol. 50, Mar., pp. 861–874). The author discusses the properties of northern white pine (*pinus strobus*), Idaho white pine (*pinus monticola*) and sugar pine (*pinus lambertiana*), the seasoning of timber for pattern-making, storage of timber at foundries and methods of measuring the humidity of the atmosphere.

Core and Mould Coatings. J. A. Ridderhof. (American Foundrymen's Association: Canadian Metals and Metallurgical Industries, 1942, vol. 5, Nov., pp. 327–331). The author discusses the preparation, application and advantages of facings for cores and sand moulds. Of the carbonaceous materials used in facings, graphite is the most effective. With suitable binders, liquids such as alcohol, carbon tetrachloride, petrol and lacquer can be used as the vehicle; these facings will dry in a few hours without being put into a drying oven.

The Drying Out of Synthetic Sands. N. J. Dunbeck. (Transactions of the American Foundrymen's Association, 1943, vol. 50, Mar., pp. 937–949). The author reports on an investigation of the effect of adding agents such as lithium chloride, zinc chloride, ethylene glycol, dextrine and fuel oil to naturally-bonded and synthetic moulding sands in order to reduce the rate at which the sand loses moisture. All these agents reduce the rate of drying-out of synthetic sands, and a comparatively small reduction is of appreciable benefit. Naturally-bonded sands lose more moisture in a given time, but the loss expressed as a percentage is lower than for synthetic sands, owing to the higher quantity originally present.

Fuel oil did not appreciably reduce the rate of drying in the experimental work, but the practice is of value in the foundry.

Coal Stokers for Core Ovens. A. Roberts, jun. (Foundry, 1942, vol. 70, Dec., pp. 75, 160). A brief description is given of the conversion of coal-fired core-drying ovens from manual to automatic stoking.

The Cause of Bleeding in Ferrous Castings. C. A. Zapffe. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1515: Metals Technology, 1942, vol. 9, Oct.). The author discusses the causes of the "bleeding" of ferrous ingots and castings. By bleeding is meant the rising of metal caused by reactions other than the carbon-oxygen reaction. Much evidence is submitted to show that the evolution of hydrogen is the primary cause of bleeding. The addition of nickel suppresses bleeding, whilst chromium increases it. Hydrogen alone, however, cannot form a bubble, so that another agent is necessary; that agent is probably the product of a hydrogen-oxygen reaction in most cases, but there may be other reaction products or foreign materials in the melt. Austenitic steels are less liable to bleed than ferritic steels, as the former have a higher hydrogen solubility. In certain exceptional cases, nitrogen itself may cause porosity and bleeding when present in excess; the necessary concentrations (probably $>0{\cdot}035\%$) are obtained only with difficulty, and usually result from additions of solid nitrides, *e.g.*, when adding high-nitrogen ferro-chromium for grain refinement. Under such conditions the nitrogen can be stabilised by adding a nitride-forming element such as titanium.

Studies on Center-Line Shrinkage in Steel Castings. S. W. Brinson and J. A. Duma. (Transactions of the American Foundrymen's Association, 1943, vol. 50, Mar., pp. 657–710). The authors report the results of several series of tests on a method of preventing porosity in steel castings. This method, which is known as "padding," consists of making the casting walls thicker than required, the extra metal tapering down in thickness from the feeder-heads to the bottom of the mould. The surplus metal has to be machined off afterwards. It is claimed that the absence of shrinkage defects and repairs more than compensates for the machining costs. The tests described were intended to determine the degree of taper required for different thicknesses and heights of finished wall, the effect of casting plates with the mould lying at different angles and the influence of other factors in the moulding practice. Inclining the mould at various angles does not alter the extent of the shrinkage, but it changes its form and location; the nearer a section approaches the horizontal, the more is the shrinkage displaced towards the top or cope surface. The use of sufficient feeder metal in the form of large truncated open risers is inadequate in preventing centre-line shrinkage. The amount of padding required to eliminate shrinkage defects is a function of the height and thickness of the section. For sections 12 in. high the amount varies inversely with the thickness,

from 2·60 in. per ft. on 1-in. thick sections to 0·15 in. per ft. on 4-in. thick sections. Sections of the same height but thicker than $4\frac{1}{2}$ in. require no padding.

Some Effects of Phosphorus on Cast Iron. M. Fielden. (Iron and Steel, 1943, vol. 16, Feb., pp. 214–217). The author discusses how increasing the phosphorus in cast iron affects its structure and properties. The replacing of an iron containing 0·3% of phosphorus for pressure-resistant castings with one containing 1% demands almost a new foundry technique. In normal grey irons, phosphorus is present mainly in a binary eutectic formation containing about 10% of phosphorus, this binary eutectic resulting from the breakdown of a ternary eutectic of iron, cementite and iron phosphide. It is generally found in practice that relatively high silicon is required to balance high phosphorus if chill-centres are to be avoided. Increasing the phosphorus extends the freezing range, a condition which results in porous defects. On account of the high carbon content of cast iron, only a small proportion of the phosphide is likely to be present in solution. Roughness on castings, especially on parts remote from the gate, has been traced to the phenomenon of phosphide " sweat." A sample of sweat-beads with sand entrained in them was tested, and 54% of the bulk could be removed with a magnet. The globules were rich in phosphorus, had more total carbon than the average content for the casting, and had a high proportion of carbon in the combined form; the silicon, sulphur and manganese were lower than in the mass of the casting.

Theory of Shrinkage in Gray Cast Iron. G. A. Timmons. (American Foundrymen's Association: Foundry, 1942, vol. 70, Dec., pp. 83, 166–170). The author explains the occurrence of shrinkage porosity in the solidification of grey cast iron. Considering a pool of molten iron trapped within a solid mass, when the liquid temperature is reached, the dendrites of austenite start to precipitate from the mother-liquor, and a slight contraction in volume takes place; these dendrites become intermingled, and build up a lattice within the liquid; as the contraction due to the change from liquid to solid continues, the level of the liquid iron is lowered and the dendrites at the top of the original pool are exposed and the unfilled spaces between them become voids. With a large volume of trapped metal, a low-melting-point eutectic, a low surface tension and a slow rate of cooling, larger dendrites will be formed and the larger will be the shrinkage voids.

Factors Influencing the Fluidity of Cast Iron. G. Burgess. (Institute of British Foundrymen: Foundry Trade Journal, 1943, vol. 69, Mar. 11, pp. 197–203). The author discusses how temperature, composition, oxide skin and viscosity affect the fluidity of cast iron, as well as some results of cast spiral fluidity tests. For a given composition, increasing the temperature increases the fluidity, but increasing the total carbon will more than counteract the effect of higher temperatures. With a soft iron with 3·9% of total carbon

the fluidity is at a minimum when the furnace attains maximum temperature at the beginning of the day's run. As the volume of slag in the furnace increases, the amounts of total and graphitic carbon become less and the fluidity increases. High-silicon, high-phosphorus irons have maximum fluidity with fairly low total carbon, *e.g.*, about 3·4%. Low-phosphorus hematite irons with silicon plus phosphorus at about 1·5% have maximum fluidity with about 3·85% of total carbon. The evidence supports the theory that maximum fluidity is attained at eutectic carbon composition. Increasing the silicon increases fluidity to the point when eutectic carbon composition is reached, but adding still more silicon would probably decrease the fluidity, because it would cause an increase in the graphite carbon. In conclusion, some tests made by casting small spirals with three different kinds of iron are described, the results confirming the author's theories.

Bakelite Plastics and Sealing Solutions—Reclaiming Porous Castings. W. Bowman. (Institute of British Foundrymen : Foundry Trade Journal, 1943, vol. 69, Feb. 18, p. 135). The author briefly describes two methods by which the pores in faulty castings can be sealed with bakelite solutions V.1845 and N.2106. In the first, for small castings, the sealing solution is forced into the casting by external pressure ; the casting is placed in a strong container from which the air can be evacuated, the sealing solution is allowed to run in from a storage vessel until the castings are covered, after which pressure is exerted for a convenient time ; the solution is thus squeezed into the body walls of the casting, filling the pores. After removal from the container, the casting is baked. In the case of large hollow castings, an example may be taken of one having several outlets. All but one of these apertures are closed, and the remaining one is used as a port for filling the casting with the sealing solution. The casting may be either trimmed or untrimmed, as final machining can be carried out after sealing. When the hollow casting is filled with the solution, air pressure is applied at the open port, so that the solution is forced from the interior into the pores of the metal. Pressure from 50 to 250 lb. per sq. in. can be applied. If any porosity exists, sweating will occur on the outside surface of the casting. After complete impregnation, the casting is baked to polymerise the bakelite.

PRODUCTION OF STEEL

(Continued from pp. 155 A–159 A)

Producing Gun and Armour Steel. D. O. Davis. (American Society for Metals : Canadian Metals and Metallurgical Industries, 1942, vol. 5, Nov., pp. 322–327). The author gives a brief descrip-

tion of the plant and operations at Dominion Foundries and Steel Ltd., Hamilton, Ontario. The principal divisions of the plant are the melting shop, steel foundry, gun shop, hot and cold mills, tin-plate department and armour-plate division.

Steel-Making Expansion in South Africa. (Engineer, 1943, vol. 175, Feb. 19, pp. 157–159). A description is given of the Iscor Works of the South African Iron and Steel Industrial Corporation at Pretoria, where important extensions are being built. A third blast-furnace to produce 600 tons of iron per day is in course of erection; in conjunction with this there will be a new coke-oven battery and extensions to the existing by-product plant. Additions are being made to the steel-melting plant, embracing two 25-ton acid Bessemer converters, a 750-ton inactive mixer and two additional 110-ton cranes. All this plant will take up almost the whole of the site at Pretoria. In view of the manner in which the industrial development in South Africa is bound to increase, the Corporation has purchased a site about 6 miles from the river Vaal and the same distance from Vereeniging. A complete new steel-works is to be built on this site. It has already been decided to proceed in the first instance with the construction of a heavy plate-mill and such works services as are required for its operation.

Bessemer Converter can be Used to Control the Price of Scrap. J. O. Griggs. (Blast Furnace and Steel Plant, 1942, vol. 30, Oct., pp. 1123–1125, 1130). The author discusses the advantages of using the Bessemer converter in conjunction with tilting open-hearth furnaces for steel-making. Among these is the ability to use low-grade scrap in the blast-furnace rather than in the steel furnace.

How Can the Laws of Statics be Applied to the Design and Development of Furnace Roofs? G. Neumann. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, Apr., pp. 437–445). The necessity of investigations relating to the design of furnace arches is made clear. Systematic observations and measurements of the behaviour of arches under prolonged heat as well as while heating up and cooling down are necessary. The application of the laws of statics to an arch not carrying a load is discussed in this paper. The determination of the line of force is shown with numerous examples. A line of force forming the arc of a circle is unsuitable for open-hearth furnace roofs. The only furnace arch design which is statically correct for an unloaded furnace arch is one such that the centres of gravity of the bricks form an inverted catenary curve.

FORGING, STAMPING AND DRAWING

(Continued from p. 160 A)

Production of Anchors and Anchor Chain. (Machinery, 1943, vol. 62, Mar. 18, pp. 288–293). Descriptions are given of the methods of making stockless anchors and stud link anchor chain at the works of the Baldt Anchor Chain & Forge Co., Chester, U.S.A. Each stud link is made up of two forged half links forged together.

The Heating of Wire While It Is Being Drawn. E. Siebel and R. Kobitzsch. (Mitteilungen aus dem Vierjahresplan-Institut für Werkstofforschung: Stahl und Eisen, 1943, vol. 63, Feb. 11, pp. 110–113). In this mathematical treatise the authors develop formulæ for calculating the rise in the temperature of wire due to friction and to deformation while it is being drawn, as well as for the temperature distribution across the wire in the die and at different distances beyond it.

Temperature and Energy Conditions when Drawing through Multiple Dies. W. Lueg. (Stahl und Eisen, 1943, vol. 63, Feb. 11, pp. 113–114). The author discusses the changes in the temperature of a wire and the power consumed when obtaining a given reduction by drawing through a single die and when drawing through a series of dies. Tests were made by reducing mild-steel rods from 11·6 mm. to 10 mm. in dia. Assuming the force required to obtain this reduction in a single drawing to be 100 units, the force required for the same reduction through two dies (with exit diameters of 10·5 and 10 mm. respectively) was 116 units, and with three dies (exit diameters of 11·0, 10·5 and 10·0 mm. respectively) 138 units were required. If the most important factor is to reduce the maximum temperature of the wire, multiple dies should be used, but if the temperature is not so important as the power consumption, then drawing in a single die is to be preferred.

Cemented Carbide for the Wire Industry. I. Die Development and Manufacture. II. Manufacturing Process Described. H. Berry. (Wire Industry, 1943, vol. 10, Jan., pp. 33–35; Feb., pp. 75–77, 81; Mar., pp. 125–127). The author points out the limitations of diamonds for wire-drawing dies, discusses German research on cemented carbide dies and describes in detail the cold-pressing method of making tungsten-carbide dies. This process may be divided into eight phases, as follows: (1) Selection of the raw materials; (2) preparation of the tungsten carbide; (3) mixing and grading the constituents with a suitable bond in a ball mill; (4) addition and mixing of a suitable lubricant to produce the required consistency; (5) pressing to shape in prepared moulds; (6) pre-sintering; (7) shaping; and (8) final sintering. The properties and general characteristics of tungsten carbide are discussed.

PYROMETRY

(Continued from pp. 131 A–132 A)

Salt Bath Temperature Control. (Steel, 1942, vol. 111, Dec. 28, p. 60). A description, together with a wiring diagram, is given of a fully automatic temperature control and recording system for use on a gas- or oil-fired salt-bath heat-treatment installation.

Temperature Measuring Instruments. A. Linford. (Engineering and Boiler House Review, 1943, vol. 57, Feb., pp. 34–37, 52). Continuation of a series of articles (*see* p. 131 A). In this part the author explains the theory of radiation pyrometers as used with the eye and with photo-electric recording apparatus; factors affecting the accuracy of the temperature measurements are discussed.

British Standard Code for Temperature Measurement. (British Standards Institution, No. 1041–1943). This temperature-measurement code is issued for the convenience of engineers responsible for the control and testing of heat-using plant. The first section is, in effect, a condensed version of the whole, and is intended as an introduction to the problem of temperature measurement for engineers without special training in this branch of physical science. Part I., Sections B, C and D, are intended to assist in the selection of the method of temperature measurement. Parts II. to V. set out in detail the construction and use of instruments for each of the fundamental thermometric systems. Part VI. deals with the electrical instruments employed. Parts VII. to XII. are to a great extent incomplete, and are only a sketch of the survey of thermometric problems encountered in industry. Finally, Part XIII., which deals with calibration, is largely based on the methods used at the National Physical Laboratory.

HEAT TREATMENT

(Continued from pp. 162 A–164 A)

High-Temperature Forced-Convection Furnaces. F. P. Peters (Metals and Alloys, 1942, vol. 16, Oct., pp. 639–643). It is known that heat transfer by radiation becomes more efficient with increasing temperature, and this has limited the use of forced convection furnaces to lower temperatures. However, improved designs and materials have made it possible to apply forced convection to high-temperature heat-treatment furnaces, some of which, and their performance, are described by the author. The uniform distribution of heat and the economy in floor space for a given production with this type of furnace are its principal advantages. Its

application for heat-treating gun forgings, tubular aircraft parts, large ring gears and tools is described.

Forced Convection Heat-Treating Furnace. L. H. Remiker. (Heat Treating and Forging, 1942, vol. 28, Dec., pp. 643–644). The author describes a vertical cylindrical heat-treatment furnace supplied for heating by gas, oil or electricity, and fitted with a fan for forced circulation of the gases. A high rate of heating with the heat uniformly distributed throughout the charge is the principal advantage claimed. Special fixtures are used for certain parts, such as similar gun forgings, and the parts are easily moved in the same fixture for the hardening, quenching and tempering operations.

Wartime Metallurgy Conserves Strategic Materials. R. E. Orton and W. F. Carter. (Machine Design, 1942, vol. 14, Dec., pp. 91–95). The authors show how to apply Davenport's S-curves to the study of the hardenability of steels, and point out that, by using these curves, it can frequently be seen that a carbon steel can be used to give sufficient core hardness where an alloy steel was previously specified.

Diffusion Rate of Carbon in Iron-Carbon Alloys. R. Smoluchowski. (Physical Review, 1942, vol. 62, Second Series, Dec. 1 and 15, pp. 539–544). The author studied the effect of additions of cobalt on the rate of the diffusion of carbon in γ-iron. The experimental technique was that of welding together two rods, one with, the other without carbon, and analysing the layers parallel to the interface after an appropriate heat treatment. From the analytical data the coefficients and activation energies of diffusion were calculated. The results show that cobalt greatly accelerates the diffusion. Thus an addition of 4% of cobalt decreases the activation energy from 32,500 cal. to 30,000 cal., which, with a carbon concentration of 1 atomic-%, corresponds to an almost twofold increase in the diffusion rate. With higher carbon contents the effect of cobalt is less marked. The author thinks that the increase in the rate of diffusion of carbon brought about by cobalt is the cause of the effect of this element on the γ–α transformation, and of the increase in the depth of decarburisation of iron-cobalt alloys with increasing cobalt contents.

The Case-Hardening of Steel. (Machinery, 1943, vol. 62, Feb. 11, pp. 152–156). The mechanism of the case-hardening of steel is discussed, and details of the case-hardening and tempering treatment for a number of British Standard steels are given, together with the procedure for copper plating parts for selective hardening.

WELDING AND CUTTING

(Continued from pp. 164 A–168 A)

Weld Forging—An Aid to Production. J. Winning. (Mechanical World, 1943, vol. 113, Feb. 12, pp. 159–162). The author discusses the advantages of weld-forging, which consists of forging relatively simple components in the orthodox manner and assembling the various parts by means of welding, using special jigs for the latter operation where necessary. This technique exploits the advantages of both forging and welding and eliminates the use of elaborate dies. Some examples of components made in this manner are described.

Welding Wrought Iron. (Iron Age, 1942, vol. 150, Dec. 17, pp. 60–61). The techniques for the manual oxy-acetylene and electric welding of different thicknesses of wrought iron are described and some suitable electrodes are recommended.

Making Alloy Steel by Arc Welding. J. A. Neumann. (Steel, 1943, vol. 112, Jan. 11, pp. 74–80). The author considers the arc-welding process as a practically instantaneous method of producing alloy steel, and explains the functions of the current, the electrode core and the coating in this process. Information is given on the effects of different amounts of alloying elements in the weld metal, and the form in which these elements are incorporated in the electrode coating. The reclamation of tools by the method is dealt with.

A Quick Method of Comparing Weldability of Substitute Steels. A. B. Kinzel. (Welding Journal, 1942, vol. 21, June, pp. 286-S–287-S). The author describes a procedure for ascertaining the weldability of a substitute steel in place of a standard steel for a particular welded joint. The steps to be taken are: (1) Section the joint made in the standard steel and determine the maximum hardness of the heat-affected zone, preferably by the Vickers method. (2) Run a Jominy end-quench test on the standard steel after heating to 1700° F. and determine the distance from the end at which the hardness is the same as that found in (1). (3) Heat three strips of the standard steel to 2100° F., cool one in still air, one in an air blast and one in oil; the bar width should be $1\frac{1}{2}$ times the thickness; after heat treatment, measure the hardness of the bars, cut a standard notch across one face of each, bend, and measure the angles; interpolate for the angle corresponding to the hardness determined in (1); an index of ductility and weldability is thus obtained concerning the heat-affected zone. (4) Run a Jominy test on the substitute steel as in (2) and determine the hardness at the same distance from the end as in (2); this gives the hardness to be expected in the welding operation. (5) Prepare two or three bars of the new steel in exactly the same way as for the standard

steel in (3) and submit them to the same bond tests. Interpolate to find the angle of bend corresponding to the hardness determined in (4). A comparison of this angle with that found in (3) gives the relative weldability of the two steels for the specific conditions pertaining to the joint selected in (1).

A Quick Cheap Way of Making High-Speed Steel Tipped Tools. C. B. Ericson. (Welding Journal, 1942, vol. 21, Dec., pp. 834–835). The author describes a simple technique for welding discarded high-speed steel tools to carbon-steel shanks. The tip is clamped in position on the shank and tack-welded at one spot. The top and sides of the tip are then carefully heated up with an oxy-acetylene torch adjusted with excess acetylene. The head of the torch is held some distance away at first, and the tip is heated up slowly to 1400–1700° F., keeping the shank 300–400° F. cooler. The welding is then performed quickly, using a medium-coated low-carbon electrode with a lower amperage than is usual. Without allowing the welded end of the tool to cool down, it is placed in a hardening furnace or a forge fire, or heated with the torch, up to 2300° F.; it is then cooled in a blast of air, or quenched in oil.

Welded Demolition Bombs. J. J. Target. (Metals and Alloys, 1942, vol. 16, Oct., pp. 634–638). The author gives details of the manufacture of large bomb casings by welding. The casing is rolled into a cylindrical shape from a steel plate; the longitudinal seam is automatically welded, after which the casing is shaped to its final form by forging the nose and tail. Heat treatment is then applied, and this is followed by shot-blasting, machining, inspection and painting.

Welding Armor Plate for Combat Tanks. E. Brooker and L. L. Elliot. (Iron Age, 1943, vol. 151, Jan. 14, pp. 23–27). The authors describe tests on welded and on riveted plates forming the hulls of army tanks. These demonstrate the superior resistance, the saving in weight, and economy in labour and machine tools achieved by welded joints.

Report on a Preliminary Investigation of the Welding of Cast Iron. W. J. Driscoll. (Transactions of the Institute of Welding, 1942, vol. 5, Oct., pp. 164–173). The author presents and discusses the results reported by five different investigators of the properties of welded test-plates, $9 \times 5 \times 0{\cdot}5$ in., of an ordinary engineering grey cast iron. The plates were cut in half, divided into sets of five and butt-welded, the welding conditions being different for each set. Of the bars welded with a cast-iron rod, only the most unsound welds showed a slightly increased tendency, as compared with quite sound welds, to fracture in the transverse test through the weld metal itself. There seemed to be little relation between soundness and the degree of preheating. In all plates welded by the oxy-acetylene method, no difficulty whatever was experienced in machining.

The Welding of Cast Iron: A Review. J. G. Pearce. (Transactions of the Institute of Welding, 1942, vol. 5, Oct., pp. 156–163).

The author reviews methods of welding cast iron, pointing out in particular the relative merits of bronze welding and fusion welding with a ferrous filler rod.

The Quality of Weld Metal and of Welded Joints. E. Helin. (Jernkontorets Annaler, 1942, vol. 126, No. 11, pp. 527–548). (In Swedish). The author discusses the quality of the weld metal deposited by electrodes of different composition with different coatings. The formation of snowflakes in weld metal is due to atomic hydrogen dissolved in the steel, not to bubbles of molecular hydrogen; the atomic hydrogen can be removed by heat treatment at about 230° C. The presence of oxygen changes the proportions of hydrogen in the molecular and atomic states by increasing the former, and it is thus a deterrent to the formation of snowflakes. Longitudinal cracks often occur in fillet welds if the composition of the parent metal is unsuitable; in rimming steel such cracks occur if the carbon content exceeds 0·25–0·30%. In silicon-killed steel the danger of cracking is very marked when the carbon plus silicon content exceeds 0·20%.

Effects of Cooling Rate on the Properties of Arc-Welded Joints in Carbon-Moly 0·50 Plate. W. F. Hess. (Welding Journal, 1942, vol. 21, Dec., pp. 608-S–619-S). The author describes an investigation of the effects of different cooling rates on the tensile strength, elongation and hardness of welded joints in specimens of $\frac{3}{4}$-in. plate of steel containing carbon 0·18%, manganese 0·69% and molybdenum 0·46%. Time-temperature curves were obtained by means of thermocouples welded to the bottom of small holes in the specimens. The conclusions reached were: (1) The superimposing of cooling curves corresponding to actual welding conditions on the S-curve for a given steel provides an excellent indication of the satisfactoriness of a given set of welding conditions from the standpoint of the effect on the heat-affected zone. (2) In trying to improve the quality of this zone it is possible to apply so high a current that the properties of the weld metal are adversely affected. (3) If slow cooling is required, better properties in the weld metal will be obtained by reducing the speed of travel than by increasing the power level. (4) If still further reduction in cooling rate is required than can be obtained by reduction in travel speed or by increasing the current, preheating the plate will achieve this without sacrifice of weld quality. (5) Preheating is particularly effective in producing improved quality in the heat-affected zone of those steels which tend to transform only upon cooling below temperatures of the order of 1000° F. (6) In establishing welding conditions for different thicknesses on any given material, the portion of the cooling curve through the transformation range for the particular material should be duplicated.

How to Cut Heavy Steel Sections. R. B. Aitchison. (Welding Journal, 1942, vol. 21, June, pp. 395–398). The author makes recommendations to operators of the oxy-acetylene cutting torch

and the oxygen lance for the cutting of heavy thicknesses of steel.

Gas Cutting in Steel Mills. S. D. Baumer. (Welding Journal, 1942, vol. 21, Dec., pp. 836–838). The author gives brief descriptions of cutting up ladle skulls and piercing blast-furnace bears with the oxygen lance, and of scarfing and nicking steel billets and cutting slabs into billets with the machine- and hand-operated oxy-acetylene cutting tool.

War Speeds Propane Cutting Progress. G. E. Stedman. (Steel, 1942, vol. 111, Dec. 14, pp. 80–82, 118). The author gives some particulars of the propane supply system for cutting up scrap and cutting off sprues and risers at the works of the Dodge Steel Co., near Philadelphia. Under the conditions at this plant propane cutting has economic advantages as compared with acetylene.

MACHINING

(Continued from pp. 89 A–90 A)

Manufacture of Aircraft Gears. P. W. Brown and E. V. Farrar. (American Gear Manufacturers' Association: Iron Age, 1942, vol. 150, Dec. 24, pp. 29–34). The authors discuss some of the difficulties encountered in the design, machining and heat treatment of aero-engine gear wheels of complicated section.

Precision Machining of Large Heavy Forgings at Titusville Forge Company. (Heat Treating and Forging, 1942, vol. 28, Nov., pp. 577–580). A brief illustrated description is given of the machine shop of the Titusville Forge Co., where the boring and turning of large ships' propeller shafts are carried out.

Proper Grinding and Inspection of Tool Steels. J. E. Erb. (Iron Age, 1943, vol. 73, Jan. 9, pp. 28–32). The author discusses the causes of cracks and defects in tool steels and shows how high-carbon tool steel can be softened, but not cracked, by grinding.

PROPERTIES AND TESTS

(Continued from pp. 174 A–182 A)

Calculation of the Tensile Strength of Normalised Steels from Chemical Composition. F. M. Walters, jun. (American Institute of Mining and Metallurgical Engineers, Technical Publication No.

1532 : Metals Technology, 1942, vol. 9, Oct.). The author describes an attempt to assess the influence of alloying elements on the tensile strength of normalised steels. The results of tensile tests on a series of unalloyed steels with increasing carbon contents and on a series of nickel steels with increasing nickel contents are given, and a proposal for calculating factors for different elements is made, these factors showing the relationship between the content of the element and the tensile strength of the steel. Carbon, manganese, silicon, phosphorus, nickel and copper are uniform in their behaviour, but elements such as molybdenum, chromium, titanium, and vanadium do not always show the maximum effect of which they are capable. Aluminium and sulphur appear to have no direct effect on the tensile strength, although it may be assumed that high sulphur decreases the effect of manganese. This factor method for calculating the tensile strength of normalised steels appears to account for the combined effect of alloying elements, but its application is restricted to steels the hardenability of which is so low that little or no martensite is formed on normalising.

Tests Reveal Stress Raiser Effects. G. Sachs and J. D. Lubahn. (American Society for Metals: Machine Design, 1942, vol. 14, Dec., pp. 104–107, 190). The authors studied the effect of notches on the tensile strength of specimens of low-nickel and low-chromium-nickel steel containing 0·40% of carbon. The specimens were heat-treated, and notches were cut with an included angle of 60°, removing from 2% to 90% of the cross-section area. The maximum load divided by the original cross-section area yields a value corresponding to the ultimate strength of an unnotched specimen; this average strength is designated as "notch strength." The "notch ductility" is defined as the reduction in area of the section at the notch after failure. This paper has appeared previously in preprint form (*see* p. 95 A).

The Reduction in the Stress in Steel Bolts under Load at High Temperatures. K. Wellinger and E. Keil. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, Apr., pp. 475–478). The authors describe an apparatus, similar to that used for creep-testing, with which they obtained time-stress curves for bolts and nuts of low chromium-nickel-molybdenum steel and of plain carbon steel at 500° C. The apparatus was designed so that the load was automatically decreased when any increase in length took place above that due to tightening the nuts at the beginning of the test. The values of the residual stress in bolts after 24 hr. annealing at 500° C. showed that the material of which the nuts were made and the type of screw-thread were much more important factors than the stress in the shank and the mechanical properties of the bolt material.

The Physical Properties of Steel Wire as Affected by Variations in the Drawing Operations. H. J. Godfrey. (American Society for Testing Materials: Wire and Wire Products, 1942, vol. 17,

Dec., pp. 704–710). The author describes an investigation of the properties of a 0·67%-carbon steel wire drawn to 0·218 in., patented and then drawn with 40%, 30%, 20% and 10% reduction per draft, and of a 0·27%-carbon steel wire drawn from a 0·220-in. patented rod with 40%, 30% and 20% reduction per draft. The physical tests, which included tension, torsion, bending and bending-fatigue tests, were made at different stages of drawing from the patented condition to 97% reduction. The tensile strength and bending properties were changed considerably by the method of drawing. The lower rates of drafting resulted in improved bending properties and lower tensile strength. The physical properties of the 0·67%-carbon steel were affected to a greater extent by the rate of drafting than was the 0·27%-carbon steel. In general, the elongation and reduction of area in the tensile tests were improved by a low rate of drafting; the fatigue properties were affected in the same manner by the rate of drafting. The best combination of strength, ductility, toughness and fatigue properties was attained after drafting with 75% to 80% reduction.

The Full-Annealing of Medium- and High-Carbon Cold-Rolled Steel Strip in the Continuous Furnace. A. Pomp and G. Niebch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1942, vol. 24, No. 16, pp. 235–241). The results obtained on annealing cold-rolled strip in a continuous furnace when the strip did not have time to attain the furnace temperature have been reported previously (*see* Journ. I. and S.I., 1941, No. II., p. 11 A). In the present investigation the speed of the strip moving through the furnace was such that it reached and was held at the furnace temperature for varying lengths of time. Strips 40 × 1 mm. in section of three steels, containing carbon 0·60%, 0·83% and 1·02% respectively, were used. Thermocouples were welded on, and these passed through the heating, holding and cooling zones. The properties of continuously annealed strip and batch-annealed coils were compared. After treatment at 650° C. there was no marked falling off in the strength of 10%-reduced cold-rolled strip. After treatment at 700° C. continuously and batch-annealed strip had practically the same properties. The degree of cold-reduction affected the mechanical properties after annealing. Marked decreases in the tensile strength and elastic limit occurred on annealing 20%-reduced strip. There was a fairly uniform decrease in the elastic limit and no change in the tensile strength and elongation on increasing the holding time; in this respect the 10%-reduced strip was more affected than the strip with greater degrees of reduction. The decrease in the elastic limit was greater with increasing carbon content. Cooling more slowly had practically the same effect as prolonging the holding time.

Calculated Hardenability and Weldability of Carbon and Low-Alloy Steels. C. E. Jackson and G. G. Luther. (American Institute of Mining and Metallurgical Engineers, Technical Publication

No. 1519: Metals Technology, 1942, vol. 9, Oct.). The authors report the results of hardness surveys across sections of welded specimens of 25 plain carbon and low-alloy steels, the latter containing nickel and nickel plus chromium. M. A. Grossmann's method was used to calculate the hardenability (*see* Journ. I. and S.I., 1942, No. II., p. 219 A), and the hardenability data were related to the maximum hardness readings and the results of slow-bend tests on notched welded specimens. The relationship between the calculated hardenability and the weld ductility was not as regular as that between the calculated hardenability and the maximum hardness.

The Effect of the Grain Size on the Weldability of Steel St 52. W. Eilender, H. Arend and R. Hackländer. (Archiv für das Eisenhüttenwesen, 1942, vol. 18, Mar., pp. 419–422). The authors investigated the effect of the austenite and ferrite-pearlite grain size of the parent metal on the structure and hardness of the heat-affected zone of steel St 52 welded in the as-rolled and in the normalised state. In the as-rolled state there was no relation between the γ and α grain sizes. The transition zone next to the weld became narrower as the γ and α grain sizes decreased. The width of the heat-affected zone also became less with increasing fineness of the α grains, but there was no relation between this and the γ grain size.

Electro-Magnetic Crack Detection in Welded Tubular Structures. (Engineer, 1943, vol. 175, Feb. 26, pp. 178–179). Particulars are given of equipment developed by Reynolds Tube Co., Ltd., for detecting cracks in welded tubular structures by the magnetic powder method. The apparatus has been designed to be foolproof, so that it can be used by quite inexperienced operators.

The Bending Fatigue Strength of Alloy Steel Forgings in the Transverse and Longitudinal Directions. G. von Rössing. (Archiv für das Eisenhüttenwesen, 1942, vol. 18, Mar., pp. 407–412). The author reports the results of an investigation of the mechanical properties of forgings of five low-alloy chromium-nickel-molybdenum steels using specimens cut with and across the grain from: (*a*) The rim and core of oil-hardened bars forged down from a large ingot; (*b*) oil-hardened specimens turned from a smaller forging than (*a*); (*c*) a drop-forged connecting rod; (*d*) a forged crank-shaft. Tables are given showing the tensile properties and the impact and fatigue strengths. In tests (*b*) a high ratio (over 0·50) of fatigue strength to tensile strength was noted. In the other test series this ratio was 0·36 to 0·47 for longitudinal specimens and 0·30 to 0·38 for transverse specimens. In the somewhat similar series (*a*) and (*d*) the difference between these two ratios was also about 20–30%. In test series (*a*) and (*b*) the difference between fatigue strengths of longitudinal and transverse specimens from the core is not so great as that between specimens from the rim.

The Effect on the Endurance Limit of Submerging Resistance-Welded Fatigue Specimens in a Cold Chamber. O. H. Henry and P. L. Calamari. (Welding Journal, 1942, vol. 21, June, pp. 291-S–292-S). The present investigation is an extension of that reported by O. H. Henry and T. D. Coyne (*see* Journ. I. and S.I., 1942, No. II., p. 218 A). Data are presented on the relation between the temperature and the endurance limit of butt-welded specimens of a 0·25%-carbon steel at temperatures in the + 20° C. to – 70° C. range. The endurance limit of both the plate metal and the welds showed a marked increase as the temperature was lowered; the largest increase occurring in the – 20° C. to – 40° C. range.

Hardenability Testing of Low-Carbon Steels. R. C. Frerichs and E. S. Rowland. (Engineering Inspection, 1942, vol. 7, No. 4, pp. 4–11, 38). The authors present and discuss data obtained in the testing, by the following hardenability tests, of four carburising grades of low-alloy chromium-nickel-molybdenum steels containing about 0·20% of carbon: (*a*) Cylinders of several sizes quenched both on tongs and in a submerged water spray; (*b*) the Jominy end-quench test on carburised specimens; (*c*) the Jominy test on uncarburised specimens; (*d*) the L bar end-quench test; (*e*) the bomb method; and (*f*) the tapered cylinder test. It was apparent from the results obtained that the choice of the method of testing the carburising grades of steel is dependent on so many factors that each laboratory must make its own selection. The decision depends, as often as not, on the amount of testing to be done and the speed with which accurate results must be obtained.

Determining the Hardness of Martensite and Austenite with the Micro-Hardness Tester. H. Hanemann. (Archiv für das Eisenhüttenwesen, 1942, vol. 18, Mar., pp. 403–406). The author describes the construction of a special diamond pyramid hardness tester with which it was possible to measure impressions with a width of the order of the wave-length of light. The diamond pyramid was so finely ground that square impressions with a side of 1 micron could be made. With this instrument hardness tests were made of the austenite and martensite in carefully prepared specimens of 1·69%-carbon steel hardened by quenching in brine from 1125° C. and tempered at temperatures in the 100–650° C. range. At tempering temperatures of 200° C. and up, finely divided grey needles, difficult to distinguish, formed; at 250° C. these were so numerous that hardness determinations of the remaining austenite could no longer be made. The final transformation of the austenite thus occurs as a partial recrystallisation. Above 250° C. tempering temperature, the hardness was the same at the positions which were previously austenite as at those which were martensite. In the austenite itself the hardness was the same both close to and at a distance from the martensite; this confirms the theory that the martensite forms without any diffusion of carbon in the austenite. After several hours' tempering at 100–150° C., the hardness of the

martensite rose to more than 1100, whilst that of the austenite was only slightly changed; thus the transformation of the tetragonal to the cubic martensite is accompanied by a marked increase in hardness. After tempering at 250° C., the hardness of the martensite fell to 750, but that of the austenite decomposition products rose to the same figure, so that this treatment gave the steel mechanically uniform properties with an increase in hardness. Increasing the tempering temperature from 250° C. caused a steady decrease in the hardness.

Wear in the Sliding Friction of Metals with Special Reference to the Effect of Temperature. W. Rädeker. (Archiv für das Eisenhüttenwesen 1942, vol. 15, Apr., pp. 453–466). The author reports on an investigation of the wear of metals in sliding friction using an apparatus which permitted heat to be applied to or withdrawn from the specimens during the test. The temperature range investigated was from − 190° to + 700° C. Rubbing speeds of 1·8 and 9·5 m. per sec. were used. The metals tested included steels with carbon in the 0·04–0·73% range, cast iron, stainless chromium and chromium-nickel steels, and high-manganese steels. With most of the steels the wear at first decreased with increasing temperature, but later the wear increased. Three types of wear were observed which were accompanied by: (*a*) Flaking and scale formation; (*b*) removal of fused layers; and (*c*) the formation of oxides. With (*a*) the wear was heavy owing to the reaction between the surfaces in contact; the heat of friction or the application of external heat decreased the wear considerably. For (*b*) to occur, a high temperature at the surface layers either by friction or from an external source, or from a high rubbing speed, was necessary. When the pressure was sufficient to break down the oxide film, the rate of wear was high. The third form of wear required high temperatures and a slight deformation of the contact surfaces. The change from one form of wear to another was gradual. Data are presented showing the relationships between temperature, wear, load and rubbing speed.

Modern Permanent-Magnet Materials. H. Nathorst. (Jernkontorets Annaler, 1942, vol. 126, No. 10, pp. 471–525). (In Swedish). After an explanation of the terms used in the measurement of magnetic properties, the author reviews the literature and patents up to March, 1942, on modern permanent-magnet materials, dealing in turn with: (*a*) The influence of the properties on the design of magnets; (*b*) the theory of the nature of magnetism; (*c*) martensitic steel for magnets; (*d*) precipitation-hardened aluminium-nickel magnetic steels; (*e*) the casting of magnets of Alni steel; (*f*) various precipitation-hardened magnets; (*g*) how the new permanent-magnet materials are applied; and (*h*) the patents. The bibliography contains 74 references which are classified under the above headings.

Effects of Ladle Inoculation on an Austenitic Cast Iron. J. T. Eash. (Transactions of the American Foundrymen's Association,

1943, vol. 50, Mar., pp. 815–828). In an investigation of the effects of ladle inoculation on austenitic cast iron containing nickel 14%, copper 6% and chromium 2%, it was found that the transverse and tensile properties of heats containing 2·25% of carbon were markedly improved by ladle additions of ferro-silicon, whereas with high carbon contents only moderate improvements were obtained. The Izod impact value of all grades was improved by inoculation with silicon. Austenitic nickel-copper-chromium cast irons made with steel in the charge had superior properties, and were improved to a greater extent by inoculation than were castings made from cast-iron scrap. Dendritic graphite and carbide structures were associated with poor mechanical properties. Inoculated heats had carbides distributed at random and flake graphite.

A Study of the Embrittling Effect of Zinc upon Stainless Steel. O. H. Henry and R. W. Schroeder. (Welding Journal, 1942, vol. 21, June, pp. 287-S–290-S). The authors describe investigations of the penetration of molten zinc and Tobin bronze (copper 60%, zinc 39%, tin 1%) into 18/8 stainless steel and 12%-chromium steel, this question having arisen because of the marked embrittlement observed in welded joints on galvanised steel. The following conclusions were reached: (1) The above two steels in the cold-rolled state are subject to intergranular penetration by certain non-ferrous metals and alloys in the molten or gaseous state. (2) Zinc is more active than Tobin bronze in penetrating into 12%-chromium steel and 18/8 steel. (3) The depth of penetration depends mainly on the temperature. (4) If no external forces are applied, and internal cold-rolling stresses are the only stresses present, penetration will stop when these stresses have been relieved. (5) With 18/8 steel, the penetration seems to be intergranular only, whereas with 12%-chromium steel it is mainly intergranular with penetration into the individual grains.

Weldable Vanadium-Bearing Steels of High Strength. H. Cornelius. (Transactions of the Institute of Welding, 1942, vol. 5, Oct., pp. 177–180). An English translation is presented of a paper which appeared in Stahl und Eisen, 1940, vol. 60, Aug. 1, pp. 684–687 (*see* Journ. I. and S.I., 1941, No. II., p. 95 A).

The Effect of Manganese and Silicon on the Amount of Carbon Dissolved in Annealed Iron. C. Benedicks. (Jernkontorets Annaler, 1942, vol. 126, No. 9, pp. 379–426). (In Swedish). The author discusses the ferronite theory on the basis of determinations of the electrical resistivity of specimens of annealed steel containing from 0·02% to 1·44% of carbon, as well as the influence of the manganese and silicon contents on the resistivity. If the total carbon in iron is high (above about 0·5%) the separated ferrite crystals contain a higher percentage of carbon than when the total carbon is low; this carbon in solution enables the ferrite to hold a certain quantity of γ-iron in solution as well; this form of ferrite is known as "ferronite."

After correcting the accepted resistivity values of steel for the effects of manganese and silicon, the resistivity σ increased steadily with the total carbon content. The corrected resistivity σ_0 was particularly sensitive to the carbon equivalent of the manganese plus silicon. This suggests that the effect of manganese plus silicon is twofold, namely, that it has the well-known direct effect on the resistivity of pure iron, and that it has a hitherto unknown indirect effect, that of increasing the resistivity caused by the increased amount of carbon in solution in the ferrite. The resistivity curves indicate that the total carbon contents of 0·5%, 1·0% and 1·5% correspond to 0·07%, 0·15% and 0·22% of carbon dissolved in the ferrite. The resistivity does not depend only on what is dissolved in the iron, but also on elements dissolved in the intergranular material. The conclusion is reached that ferronite consists of α-iron holding in solution some γ-iron and saturated with about 0·25% of carbon. Annealed carbon steels can thus be divided into the two groups, ferritic and ferronitic, the dividing line between them being at about 0·5% of carbon.

The Effect of Manganese and Silicon on the Homogeneity of Hardened Carbon Steel. C. Benedicks. (Jernkontorets Annaler, 1942, vol. 126, No. 9, pp. 427–432). (In Swedish). As an extension to the investigation reported in the preceding abstract the author studied the effect of the manganese plus silicon content on hardened carbon steel. The deviation from the linear relation between the resistivity and the carbon content of low-carbon steels observed by Enlund is markedly decreased by increasing the manganese plus silicon content. When the carbon equivalent of the manganese plus silicon attains about 0·40%, the deviation almost completely disappears; this means that the distribution of carbon in the martensite can be regarded as homogeneous as soon as the above value of 0·40% is reached. This finding confirms the conclusion in the previous paper that the presence of manganese and silicon considerably increases the amount of carbon homogeneously dissolved in the iron and supplies the reason for the additions of manganese and silicon in spring steel.

Determination of the Increase in the Electrical Resistivity of Carbon Steel Caused by Precipitated Carbide; Evaluation of the Resistivity of the Carbide Itself. C. Benedicks. (Jernkontorets Annaler, 1942, vol. 126, No. 9, pp. 433–446). (In Swedish). From curves derived from many electrical-resistivity determinations the author calculates that every 1% increase of carbon in the cementite increases the resistivity by 0·7 micro-ohms per cm. and that of the ferronite (14·3 micro-ohms per cm.) by 1·2 micro-ohms. Applying Lichtenecker's law, the resistivity of cementite is found to be 24·7 micro-ohms per cm. The high values for the resistivity of cementite given in the literature are found to be due to the effect of the manganese plus silicon content, and, after correction for this, are in good agreement with the present author's finding. The diagram proposed

by Amberg in 1920, far from opposing the existence of ferronite, is now found to be in complete agreement with the ferronite theory.

The Effect of Low Nickel Contents on the Properties of High-Strength Weldable Chromium-Manganese Steel Plates. W. Eilender, H. Arend and E. Schmidtmann. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, Apr., pp. 473–474). A high-strength weldable chromium-manganese steel has already been developed as a substitute for chromium-molybdenum steel (*see* Journ. I. and S.I., 1941, No. II., p. 95 A). As nickel-bearing scrap is often used in the making of the former steel, the authors investigated the effects of from 0·15% to 0·42% of nickel in this steel on the tensile and impact strengths, its deep-drawing properties and its tendency to crack and to increase in hardness on welding. Specimens from six heats of steel containing carbon 0·15–0·31%, manganese 1·29–1·45%, chromium 0·80–0·93% and nickel 0·15–0·42% were tested. The nickel did not improve the mechanical properties. In the fine-grained state the steel can still be considered as a good high-strength weldable steel, but in the coarse-grained state it has a strong tendency to increase in hardness and to form cracks on welding.

The Effect of Phosphorus on the Growth of Cast Iron. M. N. Dastur and M. Cohen. (Transactions of the American Foundrymen's Association, 1943, vol. 50, Mar., pp. 895–917). The authors report on an investigation of the effect of phosphorus on the growth of cast iron on heating. Specimens were prepared from four cast irons containing phosphorus 0·067%, 0·13%, 0·53% and 0·94% respectively, one containing chromium and another chromium and molybdenum. Ten forms of heat treatment were devised, some at 1250° F. and others at 1500° F., and the changes in the specific volume of the specimens were determined by weighing in air and in water. The conclusions reached were: (1) Increasing the phosphorus decreases the growth, but 0·5% of chromium is more effective than 1% of phosphorus; adding 0·5% of molybdenum to the chromium does not further improve the growth resistance; (2) growth at 1250° F. is practically the same whether the heating is continuous or repeated; (3) the growth at 1500° F. is appreciably greater than that at 1250° F., and repeated heating at 1500° F. causes more growth than constant heating at 1500° F.; and (4) growth at 1250° F. in air is only slightly greater than in lead, but at 1500° F. in air it is very much greater than in lead.

Effect of the Tempering Temperature on the Mechanical Properties of Molybdenum-Free Heat-Treatable Steels. A. Krisch and W. Puzicha. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1942, vol. 24, No. 18, pp. 249–276). The authors report the results of hardness, tensile and impact tests on twelve low-alloy steels after various forms of heat treatment, the object being to establish the tempering temperatures which would result in the best mechanical properties. The twelve steels comprised two chromium-nickel steels with 0·43% and 0·56% of carbon respectively,

three manganese steels, one manganese-silicon steel, one chromium steel, one manganese-chromium steel, two chromium-vanadium steels, one manganese-vanadium steel and one manganese-chromium-vanadium steel. Specimens were cut from 60-mm. dia. bars, some in the longitudinal and some in the transverse direction. The results are given in extensive tables and many series of graphs.

User Report No. 6 on Experience with NE (National Emergency) Alloy Steels. A. S. Jameson. (Steel, 1942, vol. 111, Dec. 21, pp. 70–72, 107–108). The author reports the results of hardenability, hardness and tensile tests on specimens of the NE-8000 series of low-alloy steels which are often used for cold-heading and making into bolts and studs.

User Report No. 7 on Experience with NE (National Emergency) Alloy Steels. S. L. Widrig. (Steel, 1943, vol. 112, Jan. 11, pp. 60–62). The author describes the system of testing gear steels developed by the Spicer Manufacturing Co. This consists of an automatic gear-changing machine which makes about 19 changes per min. Gears made of the National Emergency steels after various forms of heat treatment were tested until failure of teeth occurred. So far steels NE-8600 and NE-8700 have proved to be most satisfactory for heavy-duty transmission.

The National Emergency Steels. C. M. Parker. (Metals and Alloys, 1942, vol. 16, Oct., pp. 622–629). The author discusses the development and properties of the NE-8000 series of the National Emergency steels; this series covers the molybdenum and the nickel-chromium-molybdenum steels.

NE (National Emergency) Alloy Steels. A. S. Jameson. (Steel, 1942, vol. 111, Dec. 7, pp. 112–118). The author gives details of the experience gained by the International Harvester Co., in the use of steel NE-8720 (carbon 0·18–0·23%, manganese 0·70–0·90%, nickel 0·40–0·60%, chromium 0·40–0·60% and molybdenum 0·20–0·30%) to replace steel E-4620 (carbon 0·17–0·22%, manganese 0·45–0·65%, nickel 1·65–2·00%, no chromium and molybdenum 0·20–0·30%) in the manufacture of roller bearings.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 182 A–184 A)

Investigations of the Structure of Steel with the Electron Microscope. H. Bennek, O. Rüdiger, F. Stäblein and K. E. Volk. (Archiv für das Eisenhüttenwesen, 1942, vol. 18, Mar., pp. 431–436). The authors present and discuss the results obtained using an electron microscope to examine the structure of steel specimens with different carbon contents. Stripping films were prepared by three methods, the aluminium vapour technique, the resin process

and the iron oxide process. Very good results suitable for metallographic investigations were obtained by the first two methods, but the iron oxide film was unsatisfactory owing to the interference of the iron in the film. A comparison of pictures from an aluminium film in the electron microscope with a colloid film in the optical microscope revealed that in the former the pearlite lamellæ did not appear to be so broad or to lie so obliquely as in the latter. It is thought that this difference is due to the difference in the depth of etching. The aluminium film is also probably a cleaner and more exact replica of the surface from which it is taken than is a colloid film.

The Electron Microscope. C. J. Burton, R. B. Barnes and T. G. Rochow. (Industrial and Engineering Chemistry, Industrial Edition, 1942, vol. 34, Dec., pp. 1429–1436). The authors discuss the possibilities of calibrating electron microscopes.

New Methods for Preparing Surface Replicas for Microscopic Observation. V. J. Schaefer. (Physical Review, 1942, vol. 62, Second Series, Nov. 1 and 15, pp. 495–496). The author describes three different methods for stripping surface " replica films " without immersion of the specimens in water, so that even on sensitive metallic specimens no corrosion products can be formed.

A Method of Etching Intended for the Identification of Lead in Microstructures of Free-Cutting Steel Alloyed with Lead, *i.e.*, "Ledloy." A. von Vegesack. (Jernkontorets Annaler, 1942, vol. 126, No. 12, pp. 559–567). (In Swedish). The author describes a method of etching lead-bearing steel which enables the form and distribution of the lead to be studied. The reagent is prepared by adding 2–1 parts by volume of nitric acid (sp. gr. 1·40) to 98–99 parts of absolute alcohol, with an excess of crystallised potassium iodide. A flaky precipitate is formed which is filtered off with the excess potassium iodide. This filtrate forms the reagent which is applied to the polished surface for 10–30 sec. The etched surface is carefully washed with alcohol and dried in a stream of hot air; it is extremely sensitive, and must not be touched with the fingers, cotton wool or filter paper. Under the microscope in a dark field the lead particles show up as light yellow and are easily distinguished from other inclusions. In order to produce micrographs showing the yellow particles without resorting to colour photography, an ordinary half-tone micrograph is placed beside the microscope which is focussed on the original specimen, and the spots appearing yellow on the specimen are coloured yellow by hand on the micrograph. A comparison of a polished unetched area with the same area after etching as described shows that the lead inclusions are not submicroscopic, and that they are much larger after etching, so that the formation of lead iodide is associated with a marked increase in volume. The lead content of a steel cannot therefore be determined planimetrically using this method of etching. The elongated form of the lead inclusions after cold-rolling the steel as well as the coagula-

tion of the particles after annealing at temperatures above the melting point of lead can be seen in the micrographs which are reproduced.

The Electrolytic Polishing of Metals for Microscopical Investigations. L. von Hámos. (Jernkontorets Annaler, 1942, vol. 126, No. 12, pp. 568–590). (In Swedish). After reviewing the theory of Jacquet's electrolytic method of polishing, the author describes an apparatus and procedure, which he developed after many experiments, for preparing absolutely stress-free surfaces on steel specimens for X-ray investigations as well as modifications of the process for stainless steel, copper, brass, aluminium and white metal. The effects of the following factors on the results obtained are discussed: (*a*) Composition of the specimen; (*b*) condition of the surface; (*c*) composition of the cathode and its distance from the specimen; (*d*) composition of the electrolyte; (*e*) temperature of the electrolyte; (*f*) movement of the electrolyte; (*g*) viscosity of the electrolyte; (*h*) changes in current density; (*i*) protection of the edges; and (*k*) time of treatment.

New School of Radiography. (Iron and Steel, 1943, vol. 16, Feb., pp. 230–232). An illustrated description is given of the new school of radiography in the Kodak factory which was officially opened on January 6, 1943. It includes accommodation for lectures, X-ray work, film processing, optical experiments and viewing. In order that adequate individual attention can be given, classes are limited to six students who normally take a fortnight's course.

Graphitisation of Steel Influenced by Tessellated Stresses. F. László. (Iron and Steel Institute, 1943, this Journal, Section I). The author has previously discussed the formation of self-compensated stress systems, called "tessellated stresses," in compound solids (*see* this Journal, Section I.). In the present paper the author applies the inferences there drawn to a study of the observations of Professor N. Greenwood on the graphitisation of steel wire, and finds that they support the theory that the graphite is precipitated from the ferrite matrix and is not a product of the direct decomposition of cementite.

The Magnetic Structure of Iron Crystals. W. W. Elmore. (Physical Review, 1942, vol. 62, Second Series, Nov. 1 and 15, pp. 486–493). The author describes a microscope and magnet assembly used for producing and observing powder patterns, the patterns being formed by colloidal magnetite protected by soap. A number of patterns found on demagnetised strain-free silicon-iron crystals of known orientation are illustrated and discussed. The specimens were cut from strips of transformer steel in which fairly large crystals had been grown by the strain-annealing method. A magnetic field of only 10 oersted applied normal to the specimens was sufficient to produce patterns. On account of the large demagnetisation factor of the specimens, the patterns can be considered to be characteristic of the demagnetised state. The patterns indicate layer magnetisation with alternate layers magnetised in opposite

directions, the thickness of the layers ranging from 10 to 50 μ. Superimposed on this primary layer magnetisation is a finer secondary structure, which is presumably localised near the crystal surface and attributable to dendritic regions of reversed magnetisation.

One-Phase or Two-Phase Conditions in the System Fe-Ni; Theories of Meteoric Iron and Invar. C. Benedicks. (Arkiv för Matematik, Astronomi och Fysik, 1942, vol. 28 A, No. 14). It is shown from a review of X-ray investigations of the iron-nickel system that there are two phases present in Invar and in meteoric iron, and that the higher the degree of impurity the greater is the mutual solubility of the two phases; this is in agreement with the theory that increasing the manganese plus silicon content increases the solubility of carbon in iron.

On the Expansion Hysteresis of Invar. C. Benedicks and P. Sederholm. (Arkiv för Matematik, Astronomi och Fysik, 1942, vol. 29 A, No. 6). New dilatation determinations of Invar are presented which confirm the existence of hysteresis.

The Constitutional Diagram of Chromium- and Chromium-Manganese Steels Containing Nitrogen. H. Krainer and O. Mirt. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, Apr., pp. 467–472). A ferro-chromium low in carbon was treated with ammonia at a temperature in the 700–900° C. range to impregnate it with nitrogen, and this alloy was added to a bath of chromium steel to produce a steel containing chromium and nitrogen in the proportion of 75 to 1. Specimens of 17 iron-chromium-nitrogen alloys were subjected to dilatometric, magnetic, microscopical and X-ray investigations. From the data obtained a section through the iron corner of the iron-chromium-nitrogen constitutional diagram, with chromium and nitrogen in the above proportion, was constructed. The nitrogen considerably extended both the γ-phase and the γ-α miscibility gap. With the nitrogen contents used, it required at least 30% of chromium to produce a purely ferritic structure. Similar tests, with the addition of hardness and impact tests, were made on specimens of 35 steels containing 10–35% of chromium, 2–23% of manganese and 0·11–0·44% of nitrogen. The phase boundaries for chromium-manganese-nitrogen steels in the quenched state and after annealing at 700° C. are shown in two diagrams. Nitrogen widens the stable austenitic region and moves the limit at which the brittle σ-phase appears towards higher chromium content.

The Ternary Iron-Zirconium-Sulphur System. R. Vogel and A. Hartung. (Archiv für das Eisenhüttenwesen, 1942, vol. 18, Mar., pp. 413–418). From the results of thermal, chemical and microstructural investigations the authors constructed the constitutional diagram of the Fe–FeS–ZrS_2–Fe_2Zr system. In the liquid phase there is a large miscibility gap. Zirconium sulphide (ZrS_2) was produced synthetically, and its melting point was found to be about 1550° C. The diagram for the FeS–ZrS_2 system was developed.

CORROSION OF IRON AND STEEL

(Continued from pp. 184 A–186 A)

Corrosion of Metals and Alloys by Flue Gases. L. Shnidman and J. S. Yeaw. (Industrial and Engineering Chemistry, Industrial Edition, 1942, vol. 34, Dec., pp. 1436–1444). The authors report on two series of corrosion tests on strip samples exposed to flue gases in specially designed combustion chambers, drawings of which are reproduced. In the first series of tests samples of black steel sheet, 18/8 steel and a number of non-ferrous metals and alloys were exposed for short periods to five different combustion gases, the analyses of which are given. All specimens, except those of 18/8 steel (which remained practically unaffected for a year), showed signs of attack immediately on exposure, and corrosion continued more or less rapidly throughout the test period, the black steel specimens suffering the most severe attack. In the second test series purified town gas was used to produce the fuel-gas atmosphere, and thirteen chromium and chromium-nickel steels were exposed for two years. It was found that none of the chromium-nickel steels was appreciably attacked in one year, and only a few were affected in several more months of continued exposure. After about 18 months, however, all but three of the twenty-two samples originally exposed had succumbed to the effects of the gases. The attack suddenly became so severe that perforation of some of the strips occurred within a few months of the first signs of attack. A steel specimen containing 17% of chromium and no nickel was the first of the second series to be attacked (after less than a year). Increasing the chromium content to 27% delayed the initial attack, but did not prevent subsequent severe corrosion. The susceptibility to attack of specimens of various ordinary 18/8 steels varied greatly, depending on their origin and pretreatment. A specimen of molybdenum-bearing 18/8 steel withstood the attack during the whole testing period, whilst additions of titanium and columbium did not prove effective. Specimens of 25/12 chromium-nickel steel showed relatively little sensitivity to the effects of the flue gas. If the nickel content was increased to 20%, however, the rate of attack became markedly increased. The actual corrosion of the alloy steels studied in the second series of tests was preceded by staining. This was followed by localised pitting, which continued to be so severe during the subsequent spreading of the general corrosion that some of the strips were perforated during the two years' exposure. Based on the results obtained, a table is presented indicating the expected life of numerous ferrous and non-ferrous alloys when exposed to flue gases.

The Desirability of Removing Sulphur from Gaseous Fuels for Heating Ferrous Metals. A. Preece. (Iron and Steel Institute, 1943, this Journal, Section I). The results obtained in a general

study of the high-temperature oxidation of steels are considered with special reference to the harmful effects of the sulphur content of the furnace atmosphere. There is an important difference in the mechanism of scale formation when the furnace temperature exceeds approximately 900° C.; thus, in dealing with industrial heating operations, two temperature ranges have to be considered. The results have also shown how the harmful effects of the sulphur dioxide are influenced by the composition of the steel and the furnace atmosphere. The advantages which result from partial removal of the sulphur from the fuel and the working conditions necessary for the full realisation of these advantages are indicated.

The Detection of the Susceptibility of 18-8 Steel Castings to Intergranular Corrosion. H. W. Russell, H. A. Pray and P. D. Miller. (Transactions of the American Foundrymen's Association, 1943, vol. 50, Mar., pp. 918–930). The authors describe a rapid, simple, electrolytic test for determining the susceptibility of 18/8 stainless steel to intergranular corrosion. The apparatus consists of a small lead cell which is clamped against the article to be tested. The electrolyte is a 60% sulphuric acid solution containing 5 ml. per litre of Glycyrrhiza extract. The treatment takes 3 min., and does not damage the part under test; it leaves a small dark spot on the surface. The test spot is characterised by roughness at the grain boundaries if the metal is susceptible to this form of corrosion, and in most cases this can be judged with the naked eye. The test is applicable to both wrought and cast stainless steel, and it can be applied to detect the susceptibility to corrosion at points adjacent to welds.

Huey Corrosion Test for 18-8 Steel. F. Meunier and H. M. Schnadt. (Arcos, Belgium: Metal Progress, 1942, vol. 42, Oct., pp. 564, 568, 574). The authors discuss the validity of the Huey corrosion test for stainless steels. In this test, specimens are submitted to corrosion for three periods of 48 hr. in not less than 500 c.c. of chemically pure, boiling, 67% nitric acid in a reflux condenser. Corrosion tests were carried out on fifteen welded specimens of 18/10 chromium-nickel steel in three groups of five containing carbon 0·25%, 0·50% and 0·70% respectively. All the specimens were quenched in water from 2100° F. to normalise the austenitic structure; one of each group was kept in this condition, and the other four were annealed for 1 hr. at 1110°, 1290°, 1470° and 1650° F. respectively. The fifteen blocks were examined microscopically and their electrolytic dissolution potentials were measured. The first samples, made homogeneous and austenitic by quenching, were the most corrosion-resistant. The second group, annealed at 1110° F., was slightly weakened at the grain boundaries. The third group was greatly deprived of chromium at the boundaries of the austenite grains where there was a tendency to intercrystalline corrosion. In the specimens annealed at 1470° and 1650° F., where the more numerous carbide grains had been precipitated in an

increasingly scattered large number, the diffusion of chromium was sufficiently rapid to prevent excessive exhaustion of chromium at the boundaries, and the corrosion was more evenly distributed over the whole surface and was less severe locally. It was thus found that the predictions which could be made from a microscopical examination were fully borne out by the results of the Huey test, which, as applied to welded joints, is a very searching and accurate one. The test is, however, likely to be misapplied, because for many uses of welded stainless steel equipment, the metal does not need to be of such high quality that the calculated rate of corrosion is less than 0·004 in. per month as specified in the Huey test.

The Problem of Copper and Galvanized Iron in the Same Water System. L. Kenworthy. (Journal of the Institute of Metals, 1943, vol. 69, Feb., pp. 67–90). Premature failures of galvanised hot-water tanks connected to copper circulating pipes in domestic systems led to a laboratory investigation and to an extensive examination of service installations. Rapid failures were found to be due not to direct electrolytic action, but to very slight dissolution of copper by the circulating water, severe corrosion following the subsequent deposition of this copper on the galvanised coating. A concentration as low as 0·01 part of copper in 100,000 parts of water is sufficient to cause greatly accelerated attack. This type of system is therefore only advisable for operating with waters possessing a low degree of cupro-solvency. The cupro-solvency can be reduced by lime additions, or by aeration.

First Report of the Marine Corrosion Sub-Committee of the Corrosion Committee. (Iron and Steel Institute, 1943, this Journal, Section I). The present Report is in three sections preceded by a summary. In Section A, which is introductory in character, the constitution of the Sub-Committee is stated and the scope of their investigations is discussed. The ultimate purpose of the work in hand is to establish the most efficient and economic cures for both corrosion and the fouling of the ships' hulls.

Section B, by J. C. Hudson, on raft tests, is in seven parts. Part I. is an introduction in which the purpose of the raft tests is stated. In Part II. particulars of the specimens, their preparation, painting, exposure and inspection are given. In Part III. tests on proprietary compositions at Plymouth and Caernarvon are described. In general, it is concluded from these two series of experiments that, although service tests must remain the final criterion of performance, raft tests should give a good indication of the relative merits of protective compositions, and the results of these initial series should bear a substantial relationship to the probable behaviour in the case of painting schemes applied to new construction. In Part IV. an evaluation of the tests on the effect of surface condition of the steel before painting is presented. Temporary treatments of red lead paint have led to marked improvement in performance in underwater tests. In contrast to this, temporary treatments of red iron-

oxide paint, of boiled oil, and of the first protective coat of one of the painting schemes proved to be injurious, and yielded worse results than those obtained with no temporary treatment at all. In Part V. brief details are given of some immersion tests at Caernarvon on specimens coated with compositions prepared by U. R. Evans and his collaborators for use when the painting must be done under adverse conditions, for instance, when a ship is in dry-dock in bad weather. Part VI. contains a report on tests on paints formulated by L. A. Jordan at the Paint Research Station; these paints were of simple composition, and incorporated certain substitute medium materials for others which may become difficult to obtain, *e.g.*, coumarone resin and lanolin for rosin and linseed oil respectively. In Part VII. an outline is given of the tests in hand and the probable course of future investigations. Part VIII. deals with the effect of pigment in the protective paint. In Part IX. information is given on some other marine corrosion experiments which, although not primarily concerned with ships' bottom compositions, have a bearing on the subject; these include: (*a*) Tests on protective metallic coatings for steel; and (*b*) immersion tests on unprotected ordinary and low-alloy steels.

Section C, by J. E. Harris, is devoted entirely to anti-fouling investigations, and consists of four parts. In Part I. the biological aspects of fouling are considered. The community of organisms appearing on non-toxic surfaces includes marine bacteria, seaweeds, diatoms and sessile marine animals. Such a community can be resolved into four fairly well defined layers, namely, a basal carpet, a filamentous layer, a shrub and tree layer, and marine animals. The results of some tests using paints containing mercury and copper oxides on barnacle development are given. In Part II. the rate of slime formation is discussed; this is the earliest stage of fouling, and a technique is described by which the amount of slime formation can be accurately estimated within a period of 24–48 hr. after immersion. A description is given in Part III. of the raft experiments in progress to elucidate the general principles underlying the action of anti-fouling compositions; these involve both inorganic and organic poisons in various types of paint medium. This Section is concluded in Part IV. with some notes on the results of the examination of upwards of sixty samples of fouling from ships.

New Methods for the Examination of Corroded Metal. F. A. Champion. (Journal of the Institute of Metals, 1943, vol. 69, Feb., pp. 47–66). The author describes two methods of examining corroded metal specimens. The first is a system for the macroscopic and microscopic examination and recording of results in which the effect of the personal element in the classification and assessment of corrosion has been minimised by comparison of the specimen with standard charts and by description of the corrosion in standard terms. The second method is for the quantitative measurement of the corrosion, and it depends on photographic

interpretation of a radiograph of the specimen followed by photometric estimation. A formula for calculating a "pitting index" for the simple expression of the results is explained. Both methods were developed for aluminium and aluminium alloys, but the system of macroscopic and microscopic examination, at least, should be applicable to other metals.

ANALYSIS

(Continued from pp. 143 A–145 A)

The Chemical and Physico-Chemical Analysis of Iron and Steel. Twelve Years' Advancement. E. C. Pigott. (Metallurgia, 1943, vol. 27, Jan., pp. 118–119). The author presents a bibliography of books in English on the analysis of iron and steel and related materials published since 1930 together with short reviews of several of them.

The Significance of Stray Light in Photoelectric Filter Photometers. M. N. States and J. C. Anderson. (Journal of the Optical Society of America, 1942, vol. 32, Nov., pp. 659–666). When using photoelectric filter photometers to measure the light-transmittancy of solutions for analytical purposes the concentration of the solution is related to the photometer readings by a curve called the "analytical curve." In this paper the authors describe investigations of the influence of stray light on the analytical curve.

A Note on the Application of the Hirschmüller-Bechstein Photo-Electric Colorimeter for Steel Analysis. H. Endrass. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, Apr., pp. 447–451). The author gives details of the procedures for determining the manganese, chromium, vanadium and molybdenum in steel using the Hirschmüller-Bechstein photo-electric colorimeter.

The Practical Application of Spectrochemical Methods to the Analysis of Steels. T. L. Tippell. (Iron and Steel, 1943, vol. 16, Feb., pp. 224–226). The author describes a modern, adequate, but not excessive, spectrochemical equipment for a steelworks laboratory.

Spectrochemical Determination of Silicon, Iron and Aluminium in Mineral Powders with a High Voltage Direct Current Arc. H. I. Oshry, J. W. Ballard and H. H. Schrenk. (Journal of the Optical Society of America, 1942, vol. 32, Nov., pp. 659–666). The authors describe a spectrochemical technique for the determination of silicon, iron and aluminium as oxides in powder samples. The sample required is less than 12 mg., and the method can be applied for concentrations between about 1% and 100% of the elements determined.

On Precision in Spectrochemical Analysis. H. B. Vincent and R. A. Sawyer. (Journal of the Optical Society of America, 1942,

vol. 32, Nov., pp. 686–692). The authors discuss the use of statistical methods to obtain increased accuracy in the results of spectrochemical analyses.

Systematic Identification of the Common Metallic Coatings. H. Nechamkin and A. Sanders. (Industrial and Engineering Chemistry, Analytical Edition, 1942, vol. 14, Nov., pp. 913–914). The authors describe how to make a series of spot tests, using only one drop of each reagent, in order to identify metallic coatings. The method, which takes only 5 min., can be used for coatings of any of the following metals: Chromium, tin, nickel, gold, silver, rhodium, zinc, cadmium, copper, aluminium and lead.

Rapid Analytical Processes for Control Purposes in Foundries. K. Dietrich. (Giesserei, 1943, vol. 30, Jan. 8, pp. 13–15). The author discusses the advantages and limits of accuracy of photometric determinations of alloying elements when the metal to be determined is present in minute or in large proportions.

Direct Determinations of Combined Carbon in Cast Iron and Steel. J. G. Donaldson. (Transactions of the American Foundrymen's Association, 1943, vol. 50, Mar., pp. 931–936). The author describes a rapid and accurate direct method of determining the combined carbon in iron and steel. The sample is dissolved in a dilute mixture of nitric, sulphuric and phosphoric acids containing a small amount of silver nitrate as a catalyst. Oxidation of the combined carbon is accomplished by boiling with an ammonium persulphate solution and passing the evolved carbonaceous gases and water through heated copper oxide. The carbon dioxide is absorbed in ascarite and weighed. A determination takes 15 min. The method is not applicable to chromium steels or to other alloy steels not soluble in the acid mixture used.

The Determination of Aluminium in High Nickel-Chromium Steels. S. D. Steele and L. Russell. (Iron and Steel, 1943, vol. 16, Jan., pp. 182–185, 200). The authors make recommendations for the procedure in determining aluminium in high nickel-chromium steels using 8-hydroxyquinoline as the precipitant for aluminium. The interfering elements chromium and nickel should be removed at early stages in the process; the authors adopted the method of removing the bulk of the chromium by volatilisation as chromyl chloride. There is a much greater tendency for the hydroxyquinoline reagent to precipitate from an ammoniacal solution when alcohol is the solvent than when acetic acid is employed; acetic acid is therefore preferable as the vehicle for the reagent. Some modifications to the method of E. C. Pigott (*see* Journ. I. and S.I., 1939, No. II., p. 113 A) are put forward and details of actual analyses by the authors are given.

Cobalt Determination by Photo-Electric Comparison. W. W. Clarke. (Iron Age, 1942, vol. 150, Dec. 3, p. 45). The author describes a method for the estimation of cobalt in steel using a Fisher electro-photometer. The determination is carried out in

hydrochloric acid solution in the presence of stannous chloride. Nickel does not interfere.

Use of Phosphate for Separation of Cobalt from Iron. V. North and R. C. Wells. (Industrial and Engineering Chemistry, Analytical Edition, 1942, vol. 14, Nov., pp. 859–860). Although cobalt is commonly placed in the group with manganese, zinc and nickel, not precipitated by ammonia, it has long been known that part of the cobalt will be found in the ammonia precipitate under ordinary conditions, and this feature becomes increasingly important with small percentages of cobalt such as the amount present in ores. The method of separation described in this paper is employed after making the usual dehydration of silica and an acid hydrogen-sulphide precipitation of such elements as lead, copper and tin. Iron is then removed as phosphate from an acetic acid solution at a *p*H of about 3·5. The iron thus precipitated apparently has no retentive or adsorbing power towards cobalt, and the cobalt can be completely separated by a single precipitation of the iron.

A Simplified Method for the Co-Determination of Manganese, Chromium and Vanadium. P. Dickens and G. Thanheiser. (Iron and Steel Institute, 1943, Translation Series, No. 129). An English translation of a paper on potentiometric volumetric analysis published in Mitteilunge aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1938, vol. 20, No. 3, pp. 35–41, and Archiv für das Eisenhüttenwesen, 1938, vol. 11, May, pp. 583–588. (*See* Journ. I. and S.I., 1938, No. II., p. 116 A).

Spectrophotometric Determination of Iron. J. P. Mehlig and H. R. Hulett. (Industrial and Engineering Chemistry, Analytical Edition, 1942, vol. 14, Nov., pp. 869–871). The authors describe a spectrophotometric method for the determination of iron in ores. It is based on reducing the iron with hydroxylamine and on the measurement of the transmission of light with wave-lengths of 490 and 505 mμ through the coloured solution produced by either *o*-phenanthrolene or nitro-*o*-phenanthrolene.

Polarographic Determination of Lead in Lead-Bearing Steels. G. Haim and W. C. E. Barnes. (Industrial and Engineering Chemistry, Analytical Edition, 1942, vol. 14, Nov., p. 867). The authors describe the procedure for a polarographic method of determining the lead in lead-bearing steels which takes 20 to 25 min. The accuracy for contents between 0·1% and 0·4% is ± 0·01%.

The Potentiometric Determination of Nickel and Copper in Steel. R. Weihrich. (Iron and Steel Institute, 1943, Translation Series, No. 127). This is an English translation of a paper which appeared in Archiv für das Eisenhüttenwesen, 1940, vol. 14, Aug., pp. 55–58 (*See* Journ. I. and S.I., 1941, No. II., p. 235 A).

Determination of Low Concentrations of Oxygen in Gas. J. A. Shaw. (Industrial and Engineering Chemistry, Analytical Edition, 1942, vol. 14, Nov., pp. 891–892). The author describes a method of determining concentrations of oxygen as low as several thousandths

of 1%. The equipment and chemicals are probably available in most laboratories. The determination takes about 2 hr., but no personal attention is needed for most of this period. Some results obtained using clean compressed coke-oven gas are given.

BIBLIOGRAPHY

(Continued from pp. 147 A–148 A)

ACHENBACH, A. "*Die neuzeitliche Gussputzerei in der Eisen- und Metallgiesserei.*" (Elsners Giesserei-Fachbücher (Heft 10). Pp. 159. Berlin, 1940: Elsner Verlagsgesellschaft. (Price 2.50 RM.)

AKULOV, N. S. "*Ferromagnetism.*" Pp. 188. Moscow, 1939: Gostechteoretizdat. (Price 5.25 Roubles.) [In Russian.]

BAILEY, N. P. "*Principles of Heat Engineering.*" Pp. 264. New York, N.Y., 1942: John Wiley & Sons, Inc. (Price $2.75.)

BELYAEV, S. YA. "*Mechanical Properties of Metals Used in Aircraft Construction at Low Temperatures.*" Pp. 116. Moscow and Leningrad, 1940: Oborongizdat. (Price 2.50 Roubles.) [In Russian.]

BRESGUNOV, A. M. "*Course of Metallurgy.*" Pp. 192. Moscow and Leningrad, 1939: Oborongizdat. (Price 8 Roubles.) [In Russian.]

BRICK, R. M., and A. PHILLIPS. "*Structure and Properties of Alloys.*" Pp. 227. New York and London, 1942: McGraw-Hill Book Co., Inc. (Price $2.50.)

BRITISH STANDARDS INSTITUTION. B.S. 463: 1943. "*Sockets for Wire Ropes for General Engineering Purposes.*" 8vo, pp. 12. London, 1943. (Price 2*s*.)

BRITISH STANDARDS INSTITUTION. British Standard Code 1041: 1943. "*Temperature Measurement.*" 4to, pp. 76. London, 1943. (Price 12*s*. 6*d*.)

BRITISH STANDARDS INSTITUTION. B.S. 1070: 1942. "*War Emergency British Standard Specification for Black Paint (Tar Base) for Use on Iron and Steel.*" 8vo, pp. 5. London, 1942. (Price 1*s*.)

BRITISH STANDARDS INSTITUTION. 1081: 1942. "*British Standard Test Code for Kilns for Heavy Clay Ware, Including Refractory Materials.*" 8vo, pp. 173. London, 1942. (Price 10*s*. 6*d*.)

BRITISH STANDARDS INSTITUTION. B.S. 1083: 1942. "*War Emergency British Standard Specifications for Bolts, Nuts and Set-Screws (Machine Bolts) B.S.W. and B.S.F.*" 8vo, pp. 10. London, 1942. (Price 2*s*.)

BRITISH STANDARDS INSTITUTION. B.S. 1091: 1942. "*British Standard Specification for Pressed Steel Galvanised Rainwater Gutters, Pipes and Fittings also Heavy Pressed Steel Gutters, Galvanised or Black.*" 8vo, pp. 9. London, 1942. (Price 2*s*.)

BRITISH STANDARDS INSTITUTION. BS/STA 2. "*Services Specification for Steel for Hardened and Tempered Coil Springs for Guns and Armoured Fighting Vehicles, &c.*" 4to, pp. 2. London, 1942.

CHEN, TUNG-SHENG. "*Einfluss der Schmelzüberhitzung auf die Eigenschaften eines Werkzeugstahles in Abhängigkeit vom Ofenfutter im kernlosen Induktionsofen.*" (Aachen Techn. Hochschule, Dr.-Ing.-Diss.) 4to, pp. 48. 1942.

CLARK, W. A., and B. PLEHN. "*Materials Testing and Heat Treating.*" 8vo, pp. x + 132. New York, 1942: Harper and Brothers. (Price $1.75.)

CUMMING, A. C., and S. A. KAY. "*A Text Book of Quantitative Chemical Analysis.*" Eighth revised edition. 8vo, pp. 503. Edinburgh and London, 1942: Gurney and Jackson. (Price 18*s*. 6*d*.)

ECKELT, G. "*Schutz dem Eisen.*" 4to, pp. 22. Düsseldorf, 1942: Droste-Verlag.

ESCHER, K. "*Untersuchungen an gusseisernen Gleitführungen.*" (Aachen Techn. Hochschule, Dr.-Ing.-Diss.) 8vo, pp. 30. 1942.

GARFUNKEL, S. L., and M. I. BERDNIKOV. "*Theory and Practice of Metal-Spraying Processes.*" Pp. 208. Moscow and Leningrad, 1940: Gismestprom. (Price 8.50 Roubles.) [In Russian.]

GIBB, T. R. P. "*Optical Methods of Chemical Analysis.*" (International Chemical Series.) 8vo, pp. 301. New York and London, 1942: McGraw-Hill Book Co., Inc. (Price 35*s*.)

GREGORY, E., and E. N. SIMONS. "*The Mechanical Working of Steel.*" London: Sir Isaac Pitman and Sons, Ltd. (Price 10*s*. 6*d*.)

GRÖNEGRESS, H. W. "*Brennhärten.*" (Werkstattbücher für Betriebsbeamte, Konstrukteure und Facharbeiter. Hrsg. H. Haake. Heft 89.) 8vo, pp. 64. Berlin, 1942: Springer-Verlag. (Price 2 RM.)

HOLLER, H. "*Leitfaden für Autogenschweisser.*" 15. Auflage. Pp. 306. Halle, 1940: Marhold. (Price 4.50 RM.)

KASHCHENKO, G. A. "*Metallurgy.*" Pp. 436. Moscow and Leningrad, 1940: Metallurgizdat. (Price 16.50 Roubles.) [In Russian.]

KASSEM, M. A. "*Beitrag zur Eisengewinnung durch Reduktion mit Wasserstoff.*" (Zürich Techn. Hochschule, Techn. Diss.) 8vo, pp. 62. Zürich, 1942: Diss.-Druckerei A.-G. Gebr. Leémann & Co.

KATZ, N. V. "*Metal Spraying.*" Pp. 88. Kharkov, 1940. (Price 6 Roubles.) [In Russian.]

KEMPE, H. R., and W. HANNEFORD SMITH. "*The Engineers' Year-Book of Formulæ, Rules, Tables, Data and Memoranda for 1943.*" 49th Annual Issue, revised under the direction of L. St. L. Pendred. 8vo, pp. xii + 2854 + lxxxi. London, 1943: Morgan Brothers (Publishers), Ltd. (Price 40*s*. net.)

KLEINERMANNS, F. "*Ueber die Abhängigkeit der Alterungsbeständigkeit von Stählen von der Abkühlungsgeschwindigkeit und ihre Ursache.*" (Aachen Techn. Hochschule, Dr.-Ing.-Diss.) 4to, pp. 38. 1941.

KORTÜM, G. "*Kolorimetrie und Spektralphotometrie.*" Eine Anleitung zur Ausführung von Absorptions-, Fluoreszenz- und Trübungsmessungen an Lösungen. (Anleitungen für die chemische Laboratoriumspraxis. Bd. 2.) 8vo, pp. vi + 209. Berlin, 1942 : Springer-Verlag. (Price 12.00 RM.)

LÜPFERT, H. "*Metallische Werkstoffe.*" (Lehrbücher der Feinwerktechnik. Hrsg. von K. Gehlhoff. Bd. 7.) 8vo, pp. xi + 235. Leipzig, 1942 : C. F. Winter'sche Verlagshandlung. (Price 8.80 RM.)

McADAMS, W. H. "*Heat Transmission.*" Second edition. 8vo, pp. 459. New York and London, 1942 : McGraw-Hill Book Co., Inc. (Price 31*s.* 6*d.*)

MEHRTENS, J. "*Der Giesserei-Schachtofen im Aufbau und Betrieb.*" 3. neubearb. Aufl. des Heftes "Kupolofenbetrieb" von C. Irresberger. (Werkstattbücher für Betriebsbeamte, Konstrukteure und Facharbeiter. Hrsg. von H. Haake Heft 10.) 8vo, pp. 71. Illustrated. Berlin, 1942 : Springer-Verlag. (Price 2 RM.)

MILLER, J. K. "*Forging Operations.*" Pp. 81. Scranton, Pa, 1942 : International Textbook Co. (Price 18*s.*)

MOLLOY, E. "*Press Tools.*" (Complete Engineer Series.) 8vo, pp. 108. London, 1942 : George Newnes, Ltd. (Price 7*s.* 6*d.*)

PEASE, R. N. "*Equilibrium and Kinetics of Gas Reactions : an Introduction to the Quantum-Statistical Treatment of Chemical Processes.*" 8vo, pp. ix + 236. Princeton, N.J., 1942 : Princeton University Press ; London : Oxford University Press. (Price 22*s.* 6*d.*)

PICHLER, A. A. B. "*Introduction to the Microtechnique of Inorganic Analysis.*" 8vo, pp. vii + 302. London, 1942 : Chapman and Hall, Ltd. (Price 21*s.*)

ROUSH, G. A. "*The Mineral Industry. Its Statistics, Technology and Trade during 1941.*" Vol. 50. Supplementing volumes 1 to 49. 8vo, pp. lxx + 735. New York and London, 1942 : McGraw-Hill Book Co., Inc. (Price £4 4*s.*)

SAMOKHOTSKIY, A. L. "*The Ageing of Ferrous and Non-Ferrous Metals.*" Pp. 332. Moscow and Leningrad, 1939 : Oborongiz. (Price 13.50 Roubles.) [In Russian.]

SAMOKHOTSKIY, A. L. "*The Fatigue of Ferrous and Non-Ferrous Metals.*" Pp. 200. Moscow and Leningrad, 1940 : Oborongiz. (Price 11 Roubles.) [In Russian.]

SCHIFFNER, C. "*Männer des Metallhüttenwesens.*" 8vo, pp. viii + 274. Freiberg in Sa., 1942 : Verlagsanstalt Ernst Mauckisch. (Price 2.50 RM.)

SHELOMOV, YE. N. "*Physical Chemistry of Metallurgical Processes.*" Part 1. Pp. viii + 270. Moscow, 1940: Vses. prom. akad. im. I.V. Stalina. Izd. Sektor. [In Russian.]

TREPLIN, H., O. DISCHNER and E. KUPKE. "*Was jeder Kernmacher von seiner Arbeit wissen muss!*" (Wir von der Giesserei, H. 2.) 8vo, pp. 71. Düsseldorf, 1942: Giesserei-Verlag G.m.b.H. (Price 1.75 RM.)

WOGRINZ, A., and G. BUCHNER. "*Die Galvanotechnik. Galvanostegie und Galvanoplastik.*" 5. vollst. neubearb. Aufl. des Werkes: "Die galvanischen Metallniederschläge und deren Ausführung," von H. Steinach und G. Buchner. Pp. 244. Berlin, 1940. M. Krayn. (Price 13.50 RM.)

ZYTNER, A. YA., and N. P. LAPIN. "*Treatment of Metals by Chemical and Electrochemical Colouring.*" Pp. 100. Moscow and Leningrad: Mashgiz. (Price 3.50 Roubles.) [In Russian.]

SUBJECT INDEX.

[References to the papers read before the Institute are indicated by the word *Paper* following the page number. The letter *P.* denotes a reference in Section I. of the Journal which contains the reports of the proceedings of meetings, the papers read, and the discussions thereon. The letter *A.* denotes a reference to the section dealing with abstracts.

Indexing of Alloy Steels and Other Alloys. In the indexing of alloy steels, carbon and iron are ignored and the alloying elements contained in the steel are arranged in alphabetical order; for example, all references to nickel-chromium-molybdenum steel will be found under the heading chromium-molybdenum-nickel steel. In the indexing of other alloys, carbon and iron, when present, are included in the title; iron, when present, is always mentioned first and the other elements follow in alphabetical order, carbon being in all cases mentioned last. Examples: "Iron-silicon-carbon alloys" and "iron-chromium-nickel-carbon alloys."]

NAME INDEX

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